STREAM CONDITION ALONG A DISTURBANCE GRADIENT ON KAUAI: STRENGTHENING HAWAIIAN STREAM ASSESSMENT

Prepared by:
Tetra Tech, Inc
Center for Ecological Sciences
10045 Red Run Blvd, Suite 110
Owings Mills, MD 21117

For:
Hawaii Department of Health
Environmental Planning Office
919 Ala Moana Blvd., Suite 312
Honolulu, HI 96814

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The principal authors of this report are Michael J. Paul and Kristen L. Pavlik of Tetra Tech, Inc. and Katina Henderson of the State of Hawaii, Department of Health (DOH). This report summarizes the findings of a study funded by the United States Environmental Protection Agency (USEPA) Region 9 under contract with Tetra Tech, Inc. specifically designed to investigate the response and comparability of the physical, chemical, and biological assessment methods used by the State of Hawaii DOH in assessing stream conditions. These data were also collected to assess a potential reference stream on Kauai. The DOH understands the importance of Hawaii's precious aquatic resources and is continually developing and improving methods to assure their continued protection and restoration, including methods for stream monitoring and assessment. The design of this project was assisted by input from other members of the DOH Environmental Planning Office team, including June Harrigan and Dave Penn. The USEPA also provided guidance in developing the study plan and this work was directed by Sara Roser with input from Janet Hashimoto. The field work component of this study would not have been possible without the work of Monika Mira who was our point person on Kauai and was responsible for a tremendous number of technical issues ranging from field data collection to site selection and equipment organization, not to mention field team coordination. Fieldwork was also ably completed by the combined work of a very competent field crew including: Don Heacock, Linda Koch, Eric Zentmyer, Erin Wascher, and Michael Kido. These scientists suffered heat, rain, slippery rocks, long hikes through unfamiliar terrain, and very long days to collect data that will hopefully improve the stream assessment process in Hawaii and they deserve the credit for these data. Chemical analysis was performed by the Aecos, Inc. wet chemistry lab under the able leadership of Snookie Mello. Report editing and feedback was provided by Michael T. Barbour, of Tetra Tech, Inc., and Brenda Decker, also of Tetra Tech, Inc., provided clerical support and final document preparation. The appropriate citation for this report is:

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For more information, please contact:

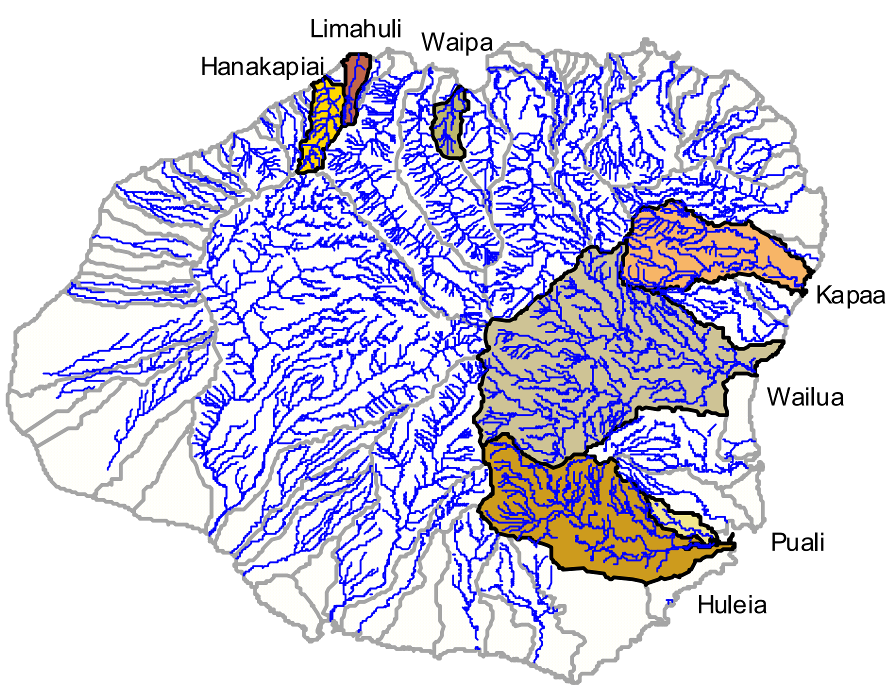
Katina Henderson
Hawaii Department of Health
Environmental Planning Office
919 Ala Moana Blvd., Suite 312
Honolulu, HI 96814

EXECUTIVE SUMMARY

Over the past half-century, land use activities such as the introduction of invasive plant species, agriculture, and urbanization have adversely impacted the quality of Hawaiian streams. The Hawaii Department of Health (DOH) is responsible for developing state water quality standards (including aquatic life use standards), identification of state 303(d) impaired waters, and development of associated TMDLs. In this capacity, they require responsive and appropriate assessment tools to examine the quality of Hawaiian streams including its chemical, physical, and biological condition, and they require that these tools be broadly applicable.

The process of assessment includes comparing conditions of impacted or potentially impacted streams to those in reference condition (presumably with little or no anthropogenic impacts). Reference conditions are the “best available” conditions where ecological potential is at its highest for a particular region or area. A robust set of reference data is a necessary component of a strong assessment program.

The **objectives of this study,** therefore, were to: **1) to provide simultaneous physical, chemical, and biological data on the condition of a Kauai reference stream; 2) to assess the responsiveness, applicability, and relationship of the DOH physical, chemical, and biological stream monitoring methods across a range of anthropogenic stress; and 3) to compare these responses across a range of stream elevations to look at the applicability of the methods to different stream sizes.**



Kauai study watersheds.

Study Design and Study Sites

In order meet the objectives of the study, a study design was created that examined physical, chemical, and biological conditions of streams along a gradient of human disturbance represented by watershed forest cover. The gradient of disturbance included a reference site, Hanakapiai stream. Hanakapiai stream drains an entirely forested watershed within the Na Pali Coast State Park and its headwaters drain the Hono'onapali Natural Area Reserve. State biologists consider it one of the least disturbed streams on the island, if not the entire state. Data collected from this site helped meet the first objective. Hanakapiai reference stream also served as one end of the human disturbance gradient, represented on the opposite end by Puali stream, draining the primarily unforested, urban city of Lihue. A number of streams between these two extremes were selected along a range of forest covers. The gradient of human disturbance allowed for analysis of the second major objective.

Watershed forested land cover was calculated for each Kauai watershed using remotely sensed land cover data analyzed with a geographic information system. Seven streams were selected along a gradient from most to least forested, with expert input from local biologists. In order to meet the third objective, three sites in each watershed, representing the three Hawaiian stream faunal zones (upper, middle, and lower elevation zones), were selected to assess the applicability and responsiveness of Hawaiian bioassessment methods across a broad range of stream types. To accomplish the study design objectives, 21 total study sites (3 each along 7 streams) were chosen. Due to access issues, it was not possible to sample one of the upper elevation sites (Upper Puali), so the final sample size was 20.

Methods – Physical, Chemical, and Biological Characterization

The Hawaii DOH has developed methods for characterizing stream physical and biological condition. We collected biological data using the Hawaii Stream Biological Protocol (HSBP), which consists of an underwater visual count of fish and several invertebrate taxa along a reach of stream split into four quadrants. The presence and abundance of the different taxa are used to calculate several metrics, which are combined into an overall site HSBP score. This score is then compared to scores from reference streams to evaluate the relative biological condition of a particular stream. There is a habitat component of the HSBP that was also used. Similar to the biological component, the habitat index combines several qualitative visually scored habitat metrics into one overall habitat index.

Data Collected

- Hawaii Stream Bioassessment Protocol (biology and habitat)
- Hawaii Stream Visual Assessment Protocol (habitat)
- Stream Chemistry
- Periphyton chlorophyll *a*

Collected for Future Analysis

- Stream benthic macroinvertebrate samples
- Stream algal community samples

The Hawaii Stream Visual Assessment Protocol (HSVAP) was used as the principal habitat index. The HSVAP combines a number of visually assessed and quantitative habitat metrics into an overall average habitat score.

In addition to biological and habitat data, chemical data was also collected from each stream. *In situ* data was collected using a multiprobe that measured temperature, dissolved oxygen, pH, and conductivity. This was combined with grab samples which were frozen and sent to a laboratory for analysis of nitrogen, phosphorus, and total suspended solids. Turbidity was estimated from grab samples analyzed in the field with a portable turbidimeter. Samples for chlorophyll *a* were collected from rock surfaces to estimate algal biomass.

Results

Objective 1 – Reference Stream Data Collection

Physical, chemical, and biological data were collected from all three elevational sites on the Hanakapiai stream. Not surprisingly, biological scores were the highest for this stream and were perfect (50/50), placing the site in the excellent category. HSBP habitat scores for this stream were above 90/100 and HSVAP scores were above 1.7/2.0 for each of the three elevational sites. Water chemistry and suspended sediments were variable among the three Hanakapiai sites, but concentrations were generally low. Chlorophyll *a* concentrations were intermediate, but likely represent the normal range for undisturbed Hawaiian streams. *In summary, the Hanakapiai stream condition was excellent and met the expectations for biological and physical condition expected for a reference stream.*

FINDINGS

- Hanakapiai stream had excellent biological and habitat quality
- The HSBP and HSVAP were responsive stream monitoring tools
- The indices were broadly applicable across elevational zones
- Chemical responses to disturbance were less clear and were not generally related to biological response

Objective 2 – Relationship of Physical, Chemical, and Biological Methods to the Disturbance Gradient

The biology and habitat indices responded significantly to the human disturbance gradient; HSBP, HSBP habitat, and HSVAP scores all decreased significantly with loss of forest cover. Values from the HSBP data identified streams ranging from Excellent to Impaired, and habitat values ranged from 94/100 to 52/100 (HSBP habitat) and 1.8/2.0 to 1.2/2.0 (HSVAP). The two habitat indices were also highly correlated, suggesting they give a comparable characterization of habitat condition. In addition, biological and habitat responses were highly correlated, which was not surprising given the similarity in their response to forest loss.

Chemical responses were far more variable. Total nitrogen, conductivity, and temperature all increased significantly with forest loss, and dissolved oxygen decreased with forest loss. All were expected based on previous studies focusing on human disturbance and stream chemical response. However, total phosphorus decreased with forest loss, which was unexpected and may be related to dynamic ecological interactions.

Objective 3 – Comparison of Responses Across Stream Faunal Zones

The responses of biology and habitat indices to disturbance were consistent across the three elevational zones, indicating that these monitoring tools have broad applicability. Only the HSBP habitat metric showed a slightly weaker response to disturbance in smaller, higher elevation streams.

Chemical responses to the disturbance gradients were not consistent across faunal zones, which was not surprising given the highly variable response of these measures to disturbance. This study used only single unreplicated measurements of chemistry and it may be that the lack of replication through time confounded the ability to see a stronger signal in chemical responses in general or across stream size. However, chemical measures generally exhibit more variability than either biological or habitat data. *These data suggest that biological and habitat measures may provide a stronger, more consistent, and more broadly applicable general stream assessment tool.*

Conclusions and Recommendations

- **Hanakapiai Stream was a model reference site**

The Hanakapiai stream represented the most forested, least disturbed landscape condition. Not surprisingly, it had the highest biological and habitat scores. This site will likely continue to stay in relatively undisturbed state and it is recommended that it continue to be monitored on a regular basis to provide more reference data and to assure its preservation. Heavy pedestrian traffic along the stream and crossing the stream should be monitored closely to limit erosion and potential impacts on its outstanding condition.

- **HSBP, HSBP habitat, and HSVAP were responsive stream monitoring tools**

The biological and habitat metrics were clearly responsive to the disturbance gradient represented by forest loss. In addition, their response was consistent across the different faunal zones. These results suggest that these metrics provide the best current stream assessment tools for Hawaii. A follow-up analysis to this one will make recommendations for areas of potential improvement in the different methods.

- **Expand the study to other islands**

While clearly responsive across a range of stream sizes, more simultaneous sampling for physical, chemical, and biological condition of streams across human disturbance gradients on multiple islands would further strengthen confidence in the broad applicability of both the HBSP and HSVAP across Hawaii. It would also contribute to the reference site database, which will help improve future index modification and development.

Locations, HSBP Scores, and narrative ratings for 21 sites on Kauai.

Site	Score	Rating
Lower Hanakapiai	50	Excellent
Lower Huleia	32	Poor
Lower Kapaa	32	Poor
Lower Limahuli	40	Good
Lower Puali	12	Impaired
Lower Wailua	36	Fair
Lower Waipa	28	Very Poor
Middle Hanakapiai	50	Excellent
Middle Huleia	14	Impaired
Middle Kapaa	24	Very Poor
Middle Limahuli	46	Excellent
Middle Puali	12	Impaired
Middle Wailua	14	Impaired
Middle Waipa	34	Poor
Upper Hanakapiai	50	Excellent
Upper Huleia/Kamooloa	16	Impaired
Upper Kapaa	34	Poor
Upper Limahuli	42	Good
Upper Wailua	22	Very Poor
Upper Waipa	38	Fair

- **Analyze benthic and algal community data**

There was a lack of consistent agreement between biological condition and water nutrient concentrations. This suggests that more data (both chemical and biological) need to be collected in order to explore potential relationships between nutrient concentration and biological response in Hawaiian streams. During this study, benthic macroinvertebrate and algal community data were also collected from the study sites (to be analyzed at a future date). These data may provide a more productive response to stream chemistry, one that could identify clearer biological response signatures to nutrient enrichment. In addition, more replicate water chemistry samples through time from sites would better characterize annual water chemical dynamics.

- **Consider the development of aquatic life use standards**

The lack of a clear relationship between water chemistry and biology, combined with the clear response of biology to forest loss suggests that direct aquatic life use standards might be a powerful tool for protecting Hawaiian stream biological integrity. A slight decrease in forested land cover is strongly associated with degraded physical habitat and biological conditions. It is recommended that the Hawaii DOH consider developing and implementing aquatic life use criteria using the HSBP or another similar index of native faunal condition as additional standards for protecting stream and watershed health in Hawaii.

LIST OF ACRONYMS AND ABBREVIATIONS

ANCOVA	Analysis of Covariance
CV	Coefficient of Variance
DOH	Hawaii Department of Health
DQI	Data Quality Indicators
DQO	Data Quality Objective
EHA	Environmental Health Administration
EPO	Environmental Planning Office
GPS	Global Positioning System
HSBP	Hawaii Stream Bioassessment Protocol
HSIBI	Hawaii Stream Index of Biotic Integrity
HSVAP	Hawaii Stream Visual Assessment Protocol
MQO	Measurement Quality Objective
NAWQA	National Water Quality Assessment Program
NRCS	Natural Resource Conservation Service
PM	Project Manager
QA	Quality Assurance
QC	Quality Control
QMH	Qualitative Multihabitat
QMP	Quality Management Plan
RSD	Relative Standard Deviation
RTH	Richest Targeted Habitat
SAP	Sampling and Analysis Plan
SD	Standard Deviation
SOP	Standard Operating Procedure
TMDL	Total maximum daily load
Tt	Tetra Tech
UVC	Underwater Visual Census
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

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1. INTRODUCTION

1.1 Background

Section 303(d) of the Clean Water Act (CWA) requires the identification of impaired waterbodies and development of implementation plans to return those waterbodies to a state of non-impairment. Those strategies typically include calculation of total maximum daily loads (TMDLs) for individual stressors (i.e., pollutants) affecting the condition of a waterbody. The initial step in the TMDL process is the determination of waterbody impairment and official listing of the waterbody on the federal 303(d) list. Varying levels of data quality and quantities currently exist in the listing process for Hawaiian streams. Therefore, a need has been identified to improve the consistency of listing criteria. This includes scientifically defensible biological monitoring and assessment methodology. The use of consistent methods will allow the Hawaii Department of Health (DOH) to confirm waterbody listing or the need for de-listing. The DOH also wants to improve the uniformity and association between biological, physical habitat, and water quality data.

1.2 Goals & Objectives

The DOH is charged with developing state water quality standards, including aquatic life use standards, production of the 303(d) impaired waters list, and development of TMDLs. Hawaii is unique, in that it has a small number of perennial streams (relative to most states), so it would be conceivable to monitor every stream, albeit on a rotating basis, over a set period of years, resources permitting. Most states can select only a subset of their streams to sample and could not possibly accomplish a complete census. However, stream sampling in Hawaii does have other constraints, including amphidromous fauna affected by both near-shore and inland water condition, and a terrain that makes some sites hard to access. Regardless, the quality of Hawaii's inland resources and potential for complete census makes the development of a strong, sound monitoring and assessment strategy critical. One cornerstone of such a program is sufficient reference site sampling, since most programs rely on reference conditions to establish the benchmark against which other assessments are measured. Increasing the number of reference sites, especially where biological, chemical, and physical data are collected concurrently is integral. It is also important to have reference sites that cover the range of stream types (physically and chemically) found across the state. The state is continuously improving its reference stream database. Therefore, sampling reference sites on Kauai was an important component of this study.

The DOH also desires to support conclusions drawn about threats to aquatic life condition from physical and chemical data and, conversely, to support conclusions about water chemistry and habitat condition potentially drawn from biological data. While chemical monitoring data are used to identify potentially detrimental chronic trends in water quality, chemical data typically represent a snapshot of stream conditions and are more variable than biological data. The timing and location of chemical sampling has a major impact on the impressions drawn from chemical data alone, and acute impacts are often missed. Habitat and biological data integrate over time and space and reflect the cumulative sum of stressors occurring over a long time period (weeks to years) and larger area (watershed above a site). Therefore, the incorporation of habitat and biological sampling into assessment programs gives a more complete picture of stream condition. However, chemical criteria are often used as surrogates for biological integrity, with certain values developed to be protective of aquatic life. On the other hand, results from biological data are often used to infer chemical or habitat stress. These assumptions require complete knowledge of the relationship between physical, chemical, and biological indicators. This study was designed to improve confidence in the linkage between physicochemical data and biological condition. This relationship, where it exists, may also be spatially dependent. Hawaii's stream biological communities are segregated by physical factors related to elevation that constrain the organisms one expects to find at a site (Kinzie et al. 1982, 1986). There are predictable changes in biological communities, therefore, along the elevation gradient, and streams are split into three major faunal zones: high, mid, and low elevation sites. Given this strong elevation effect and the changes in faunal structure along it, there was an interest in examining whether the responses of biological, chemical, and physical indicators were consistent across the different faunal zones. Therefore, there were three main objectives of this project: first, provide simultaneous habitat, chemistry, and biological data for a reference site on Kauai to increase the reference site database; second, measure habitat, chemistry, and biological data along a disturbance gradient to examine the relationship among these factors; and third, examine these relationships along disturbance gradients in high, mid, and low elevation stream segments to look for any elevation effects on the conclusions that might be drawn from these indicators.

We developed a Sampling and Analysis Plan (HI DOH, 2003) to address all of these objectives and conducted the study during a two-week sampling period (July 20 – August 2, 2003). The study was conducted on Kauai, and the eventual plan, based on the outcome of this work, is to expand the study to other islands as resources permit in the future. Twenty sites were sampled, three sites (high, mid, and low elevation) were sampled each from seven different streams on Kauai – three sites per stream (except for Puali stream where only a middle and low elevation site were sampled). The seven sites drained watersheds ranging in forested land use from fully forested (the Hanakapiai stream), which was also a state reference site, to relatively unforested (Puali stream).

2. METHODS

2.1 Selection & Geographic Distribution of Sites

Study sites were selected along a gradient in land use, since land use has consistently been shown to reflect gradients of watershed disturbance (Richards and Host 1994, Roth et al. 1996, Wang and Yin 1997, Roy et al. 2003). Land use data for Kauai was downloaded from the Hawaii Statewide GIS Program (http://www.hawaii.gov/dbedt/gis/). A combination of 2000 state land use districts, and agricultural land use maps were used to describe predominant land use on Kauai. Perennial stream data and watershed delineations were extracted from the same website. The CWRM Hawaii Stream Assessment database provided perennial stream coverage and a watershed coverage was built using smoothed 1:24,000 USGS digital elevation models. ArcView software was then used to calculate the average percent forested land cover in each watershed. Land use polygons were clipped to watershed boundaries. This calculated the area (acres) of different land use types in each watershed. Percent forested land (as defined by the state land use district land use classification) was derived as the sum of forested land area divided by total watershed area.

Seven streams were identified that varied along a gradient in watershed forested land use (Table 2-1). Decisions for the final seven-stream selection were aided by best professional judgment of local biologists familiar with the streams and with access issues (D. Heacock and M. Kido, personal communication). Since a critical consideration was to identify the consistency of the relationship among physical, chemical, and biological responses across gradient to faunal zones, three sites were selected along a gradient in elevation (low, middle, and upper) using topographic maps and the best professional judgment of the same biologists mentioned above who were also familiar with faunal zones on Kauai.

The length of each study site varied with stream width (HI DOH 2003). Stream width was estimated initially at each site using field meter tapes, and the study reach was approximately 20 times the active channel width or at least 100 m. During the field survey, actual wetted widths were measured. A detailed description of each site is given in Appendix 1.

Table 2-1. General stream site information.

Stream Name	Site Code	Date	Time	Elevation	Latitude (decimal degrees)	Longitude (decimal degrees)	% Forest Cover	Length (m)	Average Wetted Width (m)	Flood Stage
Lower Puali	LP	7/20/03	7:30-12:30	Low	22.082778	-159.358417	0	102.25	3.3	stable
Middle Puali	MP	7/20/03	14:30-17:00	Middle	21.000000	-159.093750	0	99.13	*	stable
Upper Kapaa	UK	7/21/03	11:30-17:30	Upper	22.104083	-159.393306	56	121.68	5.6	stable
Middle Kapaa	MK	7/22/03	15:00-19:00	Middle	22.101222	-159.371083	56	180	8.76	stable
Lower Kapaa	LK	7/22/03	9:00-14:30	Lower	22.104083	-159.393306	56	211.50	8.75	stable
Upper Limahuli	UL	7/23/03	11:30-14:40	Upper	22.207444	-159.579278	100	120	4.48	stable
Middle Limahuli	ML	7/23/03	15:30-18:00	Middle	22.211833	-159.576778	100	120	5.68	stable
Lower Limahuli	LL	7/26/03	10:00-12:50	Lower	*	*	100	127	6.25	stable to flood
Upper Hanakapiai	UHa	7/25/03	12:45-14:30	Upper	22.190278	-159.591972	100	179	6.43	stable
Middle Hanakapiai	MHa	7/25/03	8:30-12:30	Middle	22.199556	-159.592194	100	200	7.75	stable
Lower Hanakapiai	LHa	7/24/03	14:00-16:45	Lower	22.207333	-159.596139	100	200	8.1	stable
Upper Huleia/Kamooloa	UHu/K	7/28/03	12:30-15:30	Upper	21.991028	-159.465111	29	120	5.03	stable
Lower Huleia	LHu	7/29/03	10:00-13:40	Lower	21.912861	-159.396417	29	180	19.75	stable
Middle Huleia	MHu	7/29/03	15:30-18:00	Middle	21.960861	-159.439694	29	100	5.93	stable
Upper Wailua	UWl	7/30/03	9:45-13:00	Upper	22.062583	-159.466361	71	192.5	9.71	stable
Middle Wailua	MWl	7/30/03	15:30-18:30	Middle	22.066111	-159.443139	71	143	7.27	stable
Lower Wailua	LWl	7/31/03	11:30-15:45	Lower	22.048722	-159.367889	71	413.2	20.48	stable
Lower Waipa	LWp	8/2/03	10:00-12:30	Lower	22.196222	-159.515806	87	103.45	4.00	stable
Middle Waipa	MWp	8/1/03	10:00-13:15	Middle	22.191556	-159.518944	87	112.95	8.22	stable
Upper Waipa	UWp	8/1/03	14:00-16:30	Upper	22.185583	-159.522167	87	102.7	7.25	stable

* = no data

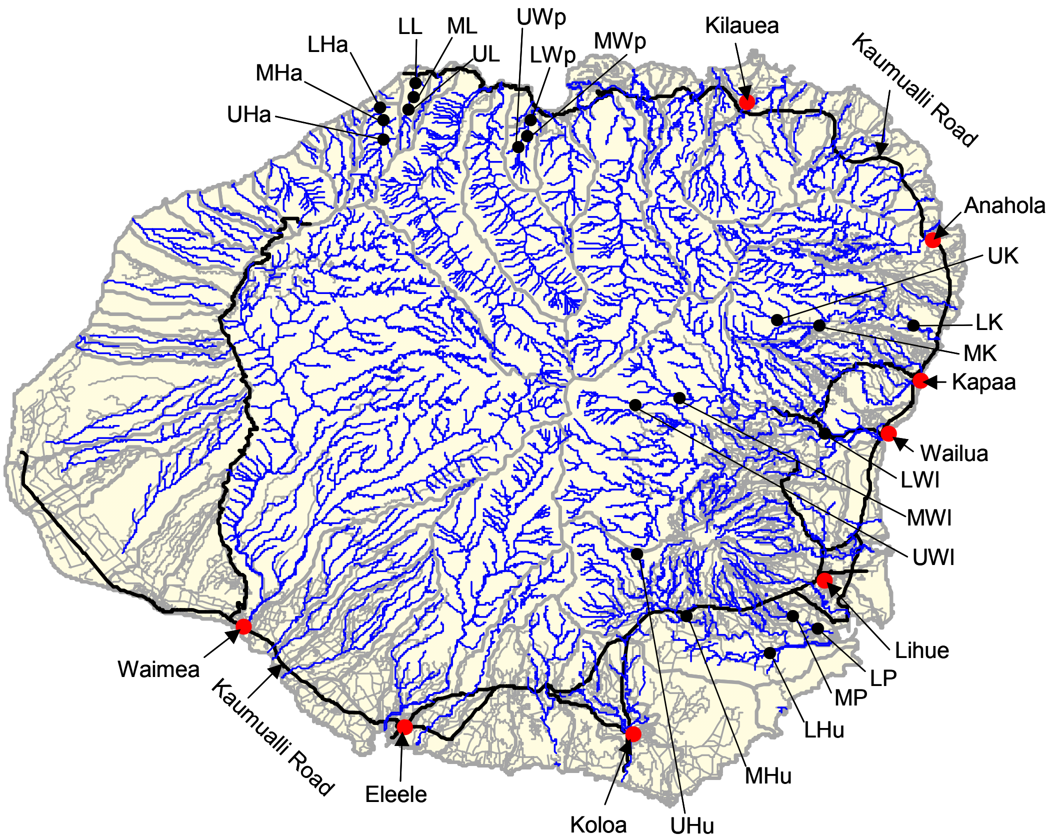

Figure 2-1. Study sites on Kauai.

2.2 Stream Sampling

All stream sampling took place on Kauai, between July 20-August 2, 2003. Sites were located in each of three gradients (i.e., upper, middle, lower) whenever possible. Puali stream was the only exception, with sites in only the lower and middle reaches (Table 2-1, Figure 2-1). Sites were located along reaches of stream with varying forest cover, from no coverage (0%), to complete coverage (100%). While sites differed in length and instream habitat availability, the following standard methods were used to assess each reach.

In-situ Chemistry

In-situ water quality was measured immediately upstream of each sampling site with a YSI Multiprobe 650QS (HI DOH 2003, Appendix C). The YSI was calibrated daily for pH and dissolved oxygen (DO), weekly for conductivity (Wilde and Radtke, 1998). The YSI was placed in the water upstream of the physical and biological sampling activity. Four chemical parameters were measured using the YSI (Table 2-2). Grab samples were taken to allow time (generally five minutes) for the YSI to equilibrate before readings were recorded. Turbidity was also measured immediately upstream of each site, using a Hach 2100P portable turbidimeter. The turbidimeter went through primary calibration while at the distributor (HI DOH 2003, Attachment 6), and was calibrated daily during the study following the secondary calibration instructions (HI DOH 2003, Attachment 6). Sample water was collected facing upstream, and the sample vial was rinsed and dried before the turbidity reading was taken.

Table 2-2. *In situ* field chemistry measurements with abbreviations used in the results.

Dissolved Oxygen (DO, mg/L)
pH
Conductance (µS/cm)
Water Temperature (T, °C)

Lab Chemistry

Grab samples were taken immediately upstream of physical and biological sampling at each site. The grabs were measured for six chemical parameters (Table 2-3). Samples for total nitrogen and total phosphorus were collected in acid-washed 250 ml open-mouth Nalgene bottles that were rinsed with deionized water before use. Samples for nitrate+nitrite, ammonia, and orthophosphate were field filtered. Grab samples were drawn into new 60 ml sterile syringes, which were rinsed three times with stream water. Samples were filtered through glass fiber filters (Gelman A/E) into acid-washed 250 ml open-mouth Nalgene bottles. Quality control grab samples were collected at two sites (Lower Kapaa and Lower Waipa) and one field blank sample was taken. Molar N:P ratios were calculated by converting the total N and total P results to molar values and calculating the ratio of the two nutrients. Total suspended solids were measured gravimetrically. A known volume of stream water was filtered through a pre-ashed, pre-weighed Gelman A/E glass fiber filter. Filters were field dried, placed in foil, dried in the lab for 24hrs at 60° C and re-weighed. Total suspended solids were recorded as total dry weight of solids retained on filters per ml of stream water sampled.

Table 2-3. Laboratory chemistry measurements. With abbreviations used in the results.

Total N (TN, µg N/L)
Total P (TP, µg P/L)
Orthophosphate (Ortho-P, µg P/L)
Ammonia (NH_4, µg N/L)
Nitrate+Nitrite (µg N/L)
Total Suspended Solids (TSS, mg/L)

Physical Habitat

Habitat evaluation was performed at each sampling site by following the modified DOH Hawaii Stream Visual Assessment Protocol (HSVAP, HI DOH 2003, Appendix D) and the Hawaii Stream Bioassessment Protocol Habitat Assessment (HSBP, HI DOH 2003, Appendix G). Habitat assessments were performed on the same reach from which biological samples were collected. The location of the sites (latitude and longitude) was measured using a GPS. Measurements were made at the 0 m point of the reach. Photographs were taken facing upstream and downstream (in each quadrant) of the reach. This general location information was collected at every primary sampling site. Duplicate HSBP habitat assessments were performed at three sites, one duplicate HSVAP habitat assessment was performed.

HSVAP

As outlined in the HI SAP (HI DOH, 2003), the Hawaii Stream Visual Assessment Protocol (HSVAP) was completed at each site (Table 2-4). General stream sampling information was completed (e.g., date, time, stream name, weather), as well as more specific reach location information such as stream type (pool-riffle, riffle-run, cascade), segment length, and temperature at each site. Upon arriving at the designated reach area, average stream widths were measured to determine the overall reach length (20 x average width, no less than 100 m). The reach was then divided into four equally-spaced quadrants, which were flagged to cover 0-25%, 25-50%, 50-75%, and 75-100% of the total reach length. Once the reach was divided into four quadrants (of similar distance), the remaining visual parameters were measured and recorded. Seven different substrate categories and five bank vegetation categories were quantified. The average percent canopy/shade was visually assessed. Average stream width and velocity depth were measured with a meter tape. Ten habitat elements describing physical habitat quality and stability were also visually assessed (HI DOH 2003, Appendix D). These parameters are based on a scale of 0 – 2, with 0 being the worst possible conditions, and 2 representing the best possible conditions. The following 10 elements were evaluated:

1. *Turbidity* – Clarity of the stream water.
2. *Plant Growth* – Measure of slight to heavy loads of nutrient enrichment or eutrophication.
3. *Channel Condition* – Measures extent of channel modification such as downcutting, placed rip-rap, and lateral cutting.

Table 2-4. HSVAP habitat categories and measurements.

Category and Definition	Finer Measurement Category
Stream Type - Cascade, step-pool; plane-bed; riffle/pool, regime, and braided (based in large part on stream gradient; Montgomery & Buffington)	
Segment Length - Measure or estimate the channel length (in meters or feet) of each Segment or habitat unit being evaluated	
Temperature - Use a hand-held thermometer in at least 3 places in the segment (include shady and open canopy areas if they occur within the segment), get an average, and enter the current stream temperature in Fahrenheit or Celsius.	
Substrate - Split your segment equally into four plots (e.g. mark off every 5 meters on your 20 meter tape), visually assess substrate within the 5-meter rectangle by estimating cover/composition.	Silt/clay Sand Gravel Cobble Rock Boulder Bedrock/Concrete
Embeddedness % - One to four representative sites in these types of habitats should be chosen along the segment. This assessment can be accomplished by picking up gravel or cobble with your fingertips and estimating what percent of the stone was buried. At least 50 measurements should be taken, then averaged to produce the overall percentage of embeddedness.	
Bank Vegetation (Right and Left Banks) - Estimate the percentage cover of trees, shrubs/saplings, herbaceous, leaf litter or bare bank viewed upstream along the left and right bank. Look at the area directly adjacent to the stream.	Trees Shrubs Herbaceous Leaf Litter None (bare)
Average Canopy/Shade - Record the average percentage of canopy cover over the active stream channel (where the water typically is, not the riparian area). Use a densiometer over the active channel, or visually assess the relative amount of shading or concealment of the stream by vegetation. For wide streams/rivers, do not consider the area where no shade is possible. The Munsel Chart guide can be used to visually assess this element.	
Velocity/Depth - Two methods can be used. (1) a guava (or an orange) can be dropped at the top of the segment and timed to the end of the segment to get meters per second, then multiply by a roughness factor of either 0.6 (for rough boundaries) or 0.8 (for smooth channels). This multiplier is important, since the guava will find the path of least resistance, and velocity in the channel varies. Do this at least ten times and take an average of the scores. OR (2) use a velocity meter at the same crossing where you measure depth. To determine depth, take at least ten measurements with your yard or meter stick at the same locations where you measured width, and average the scores.	
Flow Status - Compare the current water level to the normal water level, and record as high, normal, or low. The normal water line is the line on the bank created by natural level fluctuation as evidenced by destruction of terrestrial vegetation, litter/debris lines, shelving, and changes in soil characteristics.	High Normal Low
Scored Elements - This section involves evaluating different elements of the stream and documenting a score (from 0 to 2.0, low to high rating). Use the "Scoring Sheet for the Elements" for the rating. The total all of the scores recorded is divided by the number of elements rated for the average score (typically 10, unless for instance embeddedness is not scored because there were no riffles or runs in the segment). A general stream rating can be obtained from this score. This score can be compared over time, if more than one evaluation is done, or by segment, to determine most degraded or best segments for future restoration. The evaluation of each scored element should be carefully assessed to determine the degraded elements in the system and to identify potential restoration actions.	Turbidity Plant Growth Channel Condition Channel Flow Percent Bank Stability Canopy Riparian Condition Habitat Available Litter/Trash

4. *Channel Flow Alteration* – Measures amount and intensity of water withdrawls from the stream by way of temporary or intermittent diversions, as well as inputs from stormwater outfalls or culverts.
5. *Percent Embeddedness* – Refers to the extent to which riffles are covered or sunken into silt, mud, sand, or fine pebbles of the stream bottom.
6. *Bank Stability* – Measures the potential for soil erosion from the upper and lower stream banks into the stream.
7. *Canopy/Shade* – Measurement of shade across the active channel.
8. *Riparian Width/Condition* – Measures the width of the natural vegetation from the edge of the active channel (stream bank) out onto the flood plain.
9. *Habitat Available for Native Species* – Measures the availability of physical habitat for native Hawaiian stream organisms.
10. *Litter/Trash* – Utilizes the amount of litter, trash, and fish or animal carcasses in the stream and riparian zone to quantify stream degradation.

HSBP Habitat

The Hawaii Stream Bioassessment Protocol (HSBP) utilizes sampling protocols for two integrated indices that evaluate biotic integrity and the condition of the supporting habitat for aquatic organisms. Upon arriving at the ***The following ten physical habitat parameters were measured at each site (HI DOH 2003, Appendix G).

1. *Determination of Habitat Types* – Each reach quadrant is expected to have all habitat types expected for each respective slope gradient range (Table 2-5). As the sampler moves upstream, a running tally is kept of each of the habitat types that occur.
2. *Embeddedness* – 50 particles are measured in each quadrant to determine the degree to which cobble/boulder is buried by gravel-sized and smaller particles. Highly degraded streams tend to display severe embeddedness, while more unaltered streams tend to have few buried particles.
3. *FPOM/CPOM (Fine/Coarse Particulate Organic Matter)* – This metric evaluates the degree to which vegetative, land-derived organic matter covers the stream bottom.
4. *Velocity/Depth Combinations* – A mix of hydrologic regimes which create a variety of habitat for organisms is an important feature of stream habitat diversity. Until the highest velocity is measured, a flow meter and wading rod should be used to characterize the velocity/depth combinations in each of the four quadrants.
5. *Channel Flow Status* – This metric is meant to evaluate the degree to which water is filling the wetted-width of the channel (bank-to-bank). It is aimed at evaluating habitat degradation due to stream diversion activities. The extent to which water is flowing in the streambed, touching both banks, and filling a representative cross-section of the channel is evaluated on a scale from 0 (no flow) to 100% (bankfull flow) is estimated (Figure 2-2).

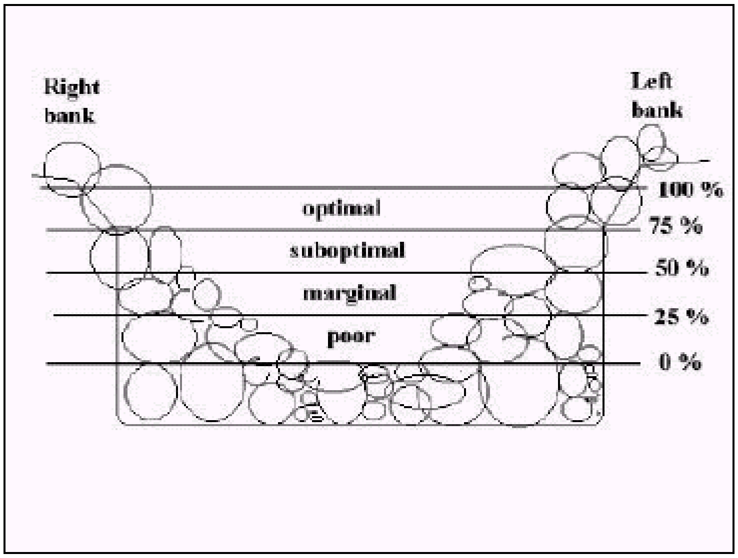

Figure 2-2. Schematic of theoretical application of channel flow status assessment metric (Kido 2002).

6 . *Channel Alteration* – Human-induced alteration to a natural channel (e.g., straightening or deepening) eliminates physical heterogeneity and destroys natural habitat important to aquatic organisms. Channels are also altered by the colonization of stream banks by invasive species, such as hau (*Hibiscus tiliaceus*), which can overgrow and alter the stream bottom with a dense cover of roots. A percentage of altered channel to total reach length was estimated through observation.
7. *Bank Stability* – Evaluates the condition of stream banks for existing or potential soil erosion. Optimal habitat conditions exist when both banks are intact and show no signs of erosion. The percentage of disturbed to total bank length was estimated through observation.
8. *Riparian Vegetative Zone Width* – Riparian zones stabilized by mature tree/shrub species prevent landscape erosion, provide surface area for nutrient transfer to the stream, and act as buffers against pollutants entering the water. Intact riparian zones support robust stream ecosystems. Functional riparian zones should be at least four times as wide as the mean stream width. The percent of riparian area with intact vegetation per quadrant was visually estimated and recorded.
9. *Riparian Understory Coverage* – Lack of ground cover or understory plants will expose or loosen soil and can become particularly severe in the case of animal-induced damage. These conditions will results in excessive soil erosion and soil transfer into the stream, degrading habitat for stream organisms. The percent of the riparian area with intact understory coverage per quadrant was estimated visually.
10. *Boulder/Cobble vs. Soil Presence* – High levels of soil presence/deposition in stream channels is symptomatic of chronic instability of stream banks, riparian zone disturbance, and/or broad scale landscape disturbance occurring in the

watershed. This metric was visually estimated in each quadrant, and recorded on the HSBP habitat data sheet.

Each metric was scored from 1 to 20 according to the protocols provided in the HSBP guidance (Kido 2002). The average metric score was calculated and represented as a percentage of 20. The velocity/depth metric scores were dropped in this analysis due to a lack of data for several sites because of velocity meter malfunction.

Table 2-5. HSBP habitat type metric definitions.

Habitat Type	Water Depth	Description
Run NOEB	Moderate to Deep (> 0.26m)	Water flowing steadily in channel, little rippling at surface, with few or no boulders visible at surface; bedrock and/or cobble/boulder bottom.
Run EB	Moderate (0.26m – 0.7m)	Water flowing steadily in channel, little rippling at surface, many boulders visible at surface, bedrock and/or cobble/boulder on bottom.
Riffle NOEB	Shallow (< 0/25m)	Water rippling at surface, cobble dominant on bottom with few or no exposed boulders visible at the surface.
Riffle EB	Shallow (0.25m)	Water rippling at surface, cobble dominant on bottom with many exposed boulders visible at the surface.
Pool – Dam	Moderate to Deep (0.26m – 0.7m)	Pool with bowl-shaped bottom, deepest point in center commonly bedrock, accumulation of cobble/boulder on downstream end, bedrock bottom.
Pool – Scour	Deep (> 0.7m)	Pool below waterfall or high cascade, bowl-shaped bottom with deep point in center, bedrock bottom.
Trans Step	Moderate – Deep (0.26m – 0.7 m)	Series of pools and large cascades forming a step in series; generally fast flowing, meandering segment of stream; bedrock bottom.
Chute	Shallow – Moderate (< 0.5m)	Stream narrows into confined channel, very fast flow, bedrock on bottom, no loose cobble.
Cascade	NA	Vertical fall of stream from 0.25m – 2m high into a dam pool or forming splash zones on boulders.
Falls	NA	Vertical fall of stream > 2m in height into a scour pool.

Biological Sampling

One biological sample was taken using the Hawaii Stream Bioassessment Protocol (HSBP, Kido 2002 and HI DOH 2003, Appendix G). Two benthic macroinvertebrate samples (HI DOH 2003, Appendix F) and one algal sample (HI DOH 2003, Appendix E) were also collected from each of the site locations in this project. The benthic macroinvertebrate and algal samples were collected but not analyzed as part of this study. Samples will be analyzed in the future when resources permit. A list of equipment and expendable supplies needed for each sampling method is also provided in Appendices E, F, and G (HI DOH, 2003).

Algae

Algal biomass was characterized using a quantitative estimate of chlorophyll *a* (chl *a*). Communities were characterized by using richness and abundance data derived from semi-quantitative samples. Revised algal-sampling protocols for quantitatively sampling algae and methods for processing collected samples in the field are based on original guidance presented by Porter et al. (1993). A number of representative, replicate cobbles were selected from the study reach and a 16 cm^2 area was scraped/brushed to remove algae. A portion of the sample was preserved for community analysis and the remainder of the sample was field filtered for chlorophyll *a* measurement (HI DOH 2003, Appendix E).

Benthic Macroinvertebrates

The sampling approach was composed of a qualitative multihabitat sampling method and semi-quantitative, targeted-habitat sampling method. A full description of the methods can be found in Appendix F (HI DOH, 2003). Table 2-6 shows the main differences and similarities between the two sampling methods. In the first, a series of samples were collected using a D-frame net with 210-µm nitex net and composited from several habitats (riffles, vegetated banks, snags, and rootwads) over 30 minutes (Qualitative Multihabitat [QMH]). Once the sampling was complete, the sample was placed into one 1L sample bottle. Once only fine (sand-sized) particles remained in the sampling bucket, they were elutriated to allow organisms to float out of the remaining sediment. Those organisms were then placed in the 1L sample bottle. Each sample was labeled on-site and preserved at the end of each day with about 10% buffered formalin, depending on how much detrital/organic material was in the sample container.

Table 2-6. Biological sampling methods.

Qualitative Multihabitat Sampling	Semi-quantitative Richest Targeted Habitat Sampling
♦ Riffle/Run	♦ Riffle
♦ Main channel/Channel Margin	✓ Mid-channel/Margin
♦ Natural/Manufactured/Bar	♦ Run
♦ 425 µm mesh	✓ Mid-channel/Margin
	♦ Pool
	✓ Mid-channel/Margin
	♦ 210 µm mesh

In the second approach, five samples were taken from coarse-grained, fast moving (i.e., riffle) habitats using a modified slack sampler (Richest-Targeted Habitat [RTH]). Riffles sampled for this approach were not re-sampled during the qualitative multihabitat sampling. The samples were similarly processed and packed in the field as the qualitative sample. Each sample was labeled on-site and preserved at the end of each day with about 10% buffered formalin, depending on the amount of organic material included in the sample.

Datasheets were completed to record each sampling effort (one for RTH samples and one for QMH samples). Information recorded included: stream name, date, time sampling started, location, time span of sampling (QMH only), samplers, and habitat types sampled, as well as other notable items specific to each site.

HSBP Biology

The Underwater Visual Census (UVC) of the Hawaii Stream Bioassessment Protocol (HSBP) was used to estimate densities and relative abundance of native fish in Hawaiian streams (Baker and Foster, 1992; Kido et al., 1994). Divers snorkeled through the entire study reach and scored the total lengths of fish observed by species, total lengths of prawn species (eye-orbit to telson), maximum shell widths of mollusk species, and numbers (but not sizes) of atyid shrimp (HI DOH 2003, Appendix G).

The Kido et al. (1994) "Line Method" was used to sample fish populations in this study. Two lines were set up in each quadrant of a sampling reach. Best professional judgment was used to place the lines over optimal fish habitat (i.e., pools and runs about 0.5 m deep), as well as in areas that would optimize the sampler's ability to survey the area. Hawaiian stream monitoring studies have shown that the highest fish densities are generally found in these optimal habitats and fish density metrics have been structured around maximum species densities expected in these habitats. Areas that had excessive exposed substrates were avoided, to minimize diver bias, observation errors, and difficulty in determining the size of the area sampled.

In the "Line Method," upstream points are identified and marked on each bank using a string that is marked off every square meter. As the sampler makes his or her way upstream in a "linear" fashion, each time a marked string is reached, the sampler observes square-meter plots from one bank to the other, following the line of the string. The line clearly delineates a contiguous grid of square-meter sized observation cells across the stream that facilitates the fish observations and ensures that the entire stream cross-section is sampled. The line also simplifies the scoring of the HSBP embeddedness and substrate characteristics metrics. Table 2-7 shows HSBP metrics and scoring, and Table 2-8, the percent breakdown for the HS-IBI (Hawaii Stream Index of Biotic Integrity).

Table 2-7. Biotic metrics and scoring used in the Hawaiian Stream Index of Biotic Integrity (HS-IBI)

	SCORING CRITERIA		
METRICS	**5**	**3**	**1**
Number of native amphidromous macrofauna (S_{NAM}) – High/Moderate Slope Mid Reach	4-3	2-1	0
Number of native amphidromous macrofauna (S_{NAM}) – Low Slope Terminal Reach	6-5	4-2	1-0
Percent Contribution Native Taxa (PNT)	100% - 75%	74% - 50%	≥ 49%
Percent Sensitive Native Fish (SNF)	≤ 50%	49% - 20%	≥ 19%
Sensitive Native Fish Density (fish sq m^{-1})²	≤ 0.46	0.45 – 0.20	≥ 0.19
Sensitive Native Fish Size (% ≥ 6.0 cm)³	≤ 50%	49% - 25%	≥ 24%
Awaous guamensis Size (% ≥ 8.0 cm)³	≤ 50%	49% - 25%	≥ 24%
Total Native Fish Density (fish sq m^{-1})	≤ 0.75	0.74 – 0.36	≥ 0.35
Community Weighted Average (CWA)	1.0 – 4.0	4.1 – 9.0	9.1 – 10
Number of Alien Taxa (NAT)	0 – 1	2 – 3	> 3
Percent Tolerant Alien Fish	0%	1% - 4%	≥ 5%
Percent Diseased or Parasitized Fish	≥ 1%	2% - 10%	≤ 11%
TOTAL POSSIBLE POINTS = 55			

Table 2-8. HS-IBI ratings, integrity classes, and class attributes.

HS-IBI Score as % of Reference	Integrity Class	Attributes
90 – 100%	Excellent	Comparable to reference conditions with minimal human disturbance; all expected native macrofauna present with alien *M. lar* either absent or in very low numbers; robust *‘o’opu* populations meeting density and size-class expectations including those for sensitive *‘o’opu* species (i.e., *‘o’opu-nopili* and/or *‘o’opu-alamo’o*); no disease or parasites observed on *‘o’opu* species.
79-89%	Good	All expected native macrofauna present; alien *M. lar* present but in low proportionate abundance (< 10%) compared to natives; total *‘o’opu* population densities generally attained but sensitive *‘o’opu* densities and/or size classes may be somewhat below expectations; < 1% of *‘o’opu* individuals with external symptoms of disease but no incidence of external leeches.
69 – 78%	Fair	Most expected native macrofaunal species present; alien *M. lar* present in substantial proportional abundance (> 10%) compared to natives, total *‘o’opu* population and sensitive species densities/size classes below expectations; < 2% of *‘o’opu* individuals with external symptoms of disease but no incidence of external leeches.
59 – 68%	Poor	Few expected native macrofaunal species present; alien *M. lar* as or more abundant than native species but other alien species absent or rare; total *‘o’opu* population and sensitive species densities/size classes well below expectations; < 10% of *‘o’opu* individuals with external symptoms of disease but no incidence of external leeches.
40 – 58%	Very Poor	Only one or two expected native macrofaunal species present and if present only in low abundance; alien aquatic species dominate the community and may include tolerant fish species (e.g., *Poeciliidae*); between 2% - 10% of *‘o’opu* individuals with external symptoms of disease and/or incidence of external leeches.
< 39%	Impaired	Native aquatic macrofaunal species absent; only alien species present including *M. lar* and tolerant fish species; > 11% of *‘o’opu* individuals with external symptoms of disease and/or attached leeches.

The following metrics were calculated from fish observations:

- *Number of Native Amphidromous Macrofauna (SNAM)* – Assesses species richness as direct counts of the number of native aquatic species found at a particular site.
- *Percent Contribution of Native Taxa (PNT)* – Another form of species richness, primarily used to evaluate the proportionate abundance of native aquatic species relative to alien species in the sample population.

  PNT = # native individuals/total # of individuals sampled

- *Percent Sensitive Native Fish (SNF)* – The proportionate abundance of *Lentipes concolor* and/or *Sicyopterus stimpsoni* in the sample population is used in this metric because of their trophic and environmental sensitivity.

  SNF = # sensitive native fish species/total # of fish in the sample population

- *Sensitive native fish density* – Supports SNF by checking absolute densities of *Lentipes concolor* or *Sicyopterus stimpsoni* depending upon which is the dominant resident species.
- *Sensitive native fish size* – The total length of *Lentipes concolor* or *Sicyopterus stimpsoni* individuals are used in this metric as an overall indicator of community health. Size is a relatively easy attribute to measure in individual fish and is influenced by both environmental (e.g., food availability/quality, pollution, etc.) as well as population/community factors (e.g., predation, competition, disease, etc.).
- *Awaous guamensis (‘o’opu-nakea) size – Awaous guamensis* is more widely distributed within/between stream systems and is also generally believed to be more tolerant to environmental degradation than *Lentipes concolor* or *Sicyopterus stimpsoni*. *Awaous guamensis* is known to rely on algae as well as invertebrates for food (Kido 1993), therefore, it is a useful indicator of the general availability of foods in the benthos.
- *Total native fish density* – Higher total fish densities correlate with more natural ecological functioning, higher environmental quality, lower numbers of alien species, and reduced human influence.
- *Community Weighted Average (CWA)* – Reflects the relative sensitivity of various taxa to water quality/habitat degradation and the relative numbers of individuals in each taxon in a sample (Hilsenhoff 1987). This metric scores the species diversity (by expected proportionate abundance) found in a stream site for its overall sensitivity to environmental stressors. The metric is calculated as:

$$CWA \ \frac{\sum n^1 a^i}{N{=}species abundance \times a^i}$$

  where n^1 is the number of individuals in the i^{th} taxon, a^i is the weighting value for that taxon, and N is the total number of individuals in the sample.

- *Number of Alien Taxa (NAT)* – Presence of alien taxa is a strong indicator of compromised stream biotic integrity. Reference streams either have no alien taxa or low numbers of *Macrobrachium lar*.
- *Percent tolerant alien fish* – Various alien fish are highly tolerant of degraded conditions, therefore, their high proportionate abundance in the fish population is indicative of high levels of human-induced degradation.
- *Percent diseased or parasitized fish* – Evaluates stream biological condition at an individual level by examining the proportion of fish sampled that have external evidence of disease. Impaired environments are correlated with high incidence of disease and/or deformities in fish (Karr, 1981) and benthic invertebrates (Hamilton and Saether, 1971).

2.3 Data Analysis

There were two main questions in this project, 1) whether there were consistent relationships among physical, chemical, and biological measures of stream condition, and 2) whether these were consistent among elevational zones. In order to answer the first question, a gradient in stream condition was created using land use as a surrogate for disturbance. Correlation analysis was applied to the data to examine the relationship between forest cover and the measured variables to establish that a gradient in disturbance had been identified. The second analysis was to compare physical, chemical, and biological measures of stream condition to address question 1. Another correlation analysis was used to analyze the relationships among physical, chemical, and biological indicators.

The third analysis, was to address question 2, a comparison of the relationship among physical, chemical, and biological measures among elevational zones. Analysis of covariance (ANCOVA) was used to look at the effects of elevation on the relationships identified using correlation. ANCOVA is designed to compare means among treatments when the response of an experimental unit may depend on its starting condition. An example would be comparing weight loss of men under different diets. In this case the diet is the treatment, but one would want to use starting weight as a covariate, since people with less weight to lose, might not be expected to lose as much. Comparing them without using ANCOVA would blur the responses. Ostensibly the slopes of the relationship are compared between initial weight and weight loss – but each diet (treatment) is a separate line. ANCOVA examines whether the slopes of lines are similar. Thus, the method allows a way of comparing slopes. In this analysis, elevation was the “treatment” and forest cover was the covariate. The test of this investigation is whether the slope of those relationships is the same or not. A significant ANCOVA value ($p<0.05$) means the slopes are significantly different.

Lastly, the physical and chemical variables which were most predictive of biological condition were identified. Multiple regression analysis was used to build models to predict condition across the disturbance gradient. Statistica software was utilized for all statistical analyses (StatSoft, Inc. 1998). Variables were transformed as necessary to meet assumptions of normality and equal variance.

2.4 Quality Assurance/Quality Control

Quality Assurance/Quality Control (QA/QC) activities are designed to ensure data quality and to document data characteristics. To this end, Hawaii has created a Sampling and Analysis Plan (SAP) for field sampling, processing, and completing chain-of-custody forms. All Standard Operating Procedures (SOPs) used during this study can be found in the Appendix of the SAP (2003). Chain-of-custody and sample log sheets were maintained to track the inventory and processing status of all samples. Sample documentation forms are maintained in the Hawaii DOH Environmental Planning Office.

Duplicate habitat and water samples were taken at three sites (Lower Kapaa, Lower Waipa, and Upper Waipa). Duplicate biological samples were not taken due to time constraints. All datasheets were checked by the QC officer at the end of each sampling day for completeness. Audits were not performed, however, the DOH QA Manager was at roughly half of the sites as a field crew member, overseeing method completion. All data, including duplicate sample data, were given to the QA manager and can be used for completing a QA report, as stipulated in the SAP.

Before analysis, 100% of the data set, once entered into Excel spreadsheets, were checked by hand against the original, hand-written field sheets by someone other than the data entry person. All discrepancies were corrected. Individual HSBP and HSVAP metrics were calculated using Access software. Hand calculations were performed on a subset of sites (10%) to check the accuracy of computer calculations.

3. RESULTS

3.1 Stream Conditions Along the Forest Gradient

3.1.1 General Response

This study was designed to examine the relationship between measures of stream biological condition made directly in each stream using the HSBP, HSVAP, and measures of water chemistry. The principal question was whether there is a sufficient correlation among these variables to support their use in stream assessment and designation. An ancillary question was whether these relationships, if they exist, were consistent across faunal zones.

A gradient design was used to attempt to establish a range in stream conditions. This gradient was based on forested land cover in watersheds. Then, watersheds were selected along the gradient in forest cover. A principal question was, therefore, whether a gradient in stream condition was established. Correlation analysis was used to investigate the relationship between forest cover and stream condition. Biology, water chemistry, and habitat all responded to reductions in forest cover (Table 3-1).

Predictably, biological condition and habitat both increased significantly with forested cover in the watershed, from low values in the least forested watersheds to highest values in the most forested watersheds (Limahuli and Hanakapiai, Table 3-2, Figure 3-1, 3-2). Commonly, biological and habitat conditions degrade as cumulative impacts associated with loss of forest cover affect streams. Agricultural and urban land uses alter the hydrology, chemistry, and physical habitat of receiving streams and the degradation of biological resources in response to these impacts has been frequently observed (Karr and Schlosser 1978, Allan 1995, Roth et al. 1996, Paul and Meyer 2001).

Other predicted responses include conductivity, which declined with forest cover, a response seen in other landscape studies (Paul and Meyer 2001). Nutrients, metals and other ions associated with urban and agricultural runoff contribute to the higher conductivities observed in less forested watersheds. On Kauai, temperatures decreased and dissolved oxygen increased with increasing forest cover. Temperature trends were not unexpected, although extrapolations from single spot measurements of temperature have to be guarded. Temperature decreases are not surprising as vegetative cover is important in cooling shallow groundwater and surface water. In addition, diversions expose more water to surficial heating. As the proportion of groundwater in a stream is reduced (through extraction or diversion), the potential for warming increases. Time of day and topography also affect stream temperature and could potentially have affected the response. However, there were no trends observed in time of day and land use relating to temperature. Dissolved oxygen is commonly impacted by organic material and/or nutrient inputs, commonly associated with less forested land cover. Lastly, nitrogen decreased as forest cover increased. Nitrogen from agricultural and urban fertilization or return flow is commonly responsible for increased nitrogen in less forested watersheds (Turner and Rabelais 1994, Meybeck 1998).

Unpredictable responses included increases in total phosphorus and chlorophyll *a* with forested land cover. Traditionally, one associates increased nutrients with forest loss (Likens et al. 1970). The volcanic soils of Hawaii are uniquely higher in phosphorus although soil concentrations vary by age and type of soil (Hedin et al. 2003). Interactions with nitrogen inputs may affect P chemistry. This is discussed in greater detail below as is the response of chlorophyll.

3.1.2 Data Comparison

The response of the water chemistry needs to be put into context. Hawaii currently has narrative standards for temperature, and numerical standards for total nitrogen and phosphorus, nitrate+nitrite, turbidity and total suspended solids [Hawaii Administrative Rules (HAR), Title 11, Chapter 54]. Values observed in this study are compared to dry season geometric mean exceedance standards, which is the average of $\log_{10}$-transformed constituent values estimated from replicate water samples collected from a stream during the dry season. These average estimates are used to account for natural variability in constituent values that occurs, and the geometric mean of samples taken during the dry season should not exceed the state standard. However, a one sample estimate, such as those in this report, do not represent a geometric mean and can not be used to estimate an exceedance. Similarly, samples are compared to the dry season 2% exceedance standard. This standard also requires a number of samples taken from a stream during the dry season to generate an accurate estimate. Values are discussed relative to the dry season geometric and 2% means here simply for relative comparison. These data cannot be used to determine whether a stream is violating or not violating a particular standard. More samples would be required to estimate whether the true geometric mean or 2% criterion was exceeded or not.

The temperature values we observed were all relatively similar (see Table 3-1) and generally increased downstream, as one would expect in a watershed. Overall site temperatures did not vary much. The highest differences within one site were in the Lower Puali stream (22.15° C – 27.4° C). The lower portion of the reach had a large falls and was fairly open, which could have impacted the temperature. Other relatively large differences between two sites sampled on the same day were noted on the middle and lower elevation of the Kapaa stream (21° C – 25.8° C). This difference could largely be attributed to the difference in time of day that each sample was taken. Sampling began at the Lower Kapaa site at 9:00am, and did not begin at the Middle Kapaa site until 3:00pm.

Total suspended solids never exceeded the dry season geometric mean criterion (10 mg/L) in any of the streams and there was no significant relationship between forested land cover and TSS among these streams (Table 3-2). For turbidity, three streams had values higher than the geometric mean summer criterion (2.0 NTU). Among these, the Middle Huleia site was highest (4.64), but the Lower Huleia and Lower Kapaa streams also had values above 2.0 (Table 3-2). However, none of the sites exceeded the 10% criterion (5.5 NTU).

Table 3-1. HSBP, water chemistry, and habitat data for each study site. Elevation refers to the location of each site along the faunal zone gradient. Forest values refer to the percent forest cover in each watershed. All values represent a single sample. HSBP habitat scores were calculated as a percent of 8 metrics since velocity/depth and embeddedness were not complete for each site. See Appendix 3 for specific habitat metric scores. Chlorophyll *a* values (mg/m2) represent a composite of 10 hard substrates sampled from the reach. Data on conductance, DO, pH, and T° for the Middle Huleia (MHu) site were lost. Nutrient data are all in µg/L, conductivity is in µs/cm , DO and TSS in mg/L, and temperature in °C.

Stations	Elevation	Forest	HSBP	Chla	NH_4	Nitrate/ Nitrite	TN	TP	N:P	Ortho-P	Cond	DO	pH	T°	TSS	NTU	HSVAP	HSBP Habitat
LHa	Low	100	50	74	<1	45	135	23	12.1	7.0	105	8.76	7.95	23.7	5.4	1.02	1.7	92.4
LHu	Low	29	32	52	<1	98	236	9	54.2	0.5	166	8.06	7.08	26.1	1.2	2.53	1.6	77.1
LK	Low	56	32	23	<1	27	153	11	28.7	1.0	133	9.13	8.30	26.2	1.8	2.16	1.2	56.7
LL	Low	100	40	77	<1	37	107	19	11.6	7.0	97	7.75	7.66	21.6	7.6	1.37	1.7	80.6
LP	Low	0	12	2.0	<1	119	208	11	39.1	1.0	162	7.00	7.91	24.7	3.0	1.80	1.5	65.1
LWl	Low	71	36	41	<1	16	89	11	16.7	0.5	111	8.49	7.46	25.7	3.8	1.72	1.8	77.2
LWp	Low	87	28	36	<1	4	48	8	12.4	2.0	112	8.94	7.01	22.7	1.4	0.74	1.3	51.5
MHa	Mid	100	50	77	<1	62	156	10	32.2	0.5	104	9.73	7.86	21.0	0.0	0.68	1.7	93.8
MHu	Mid	29	14	92	<1	62	156	10	32.2	0.5	*	*	*	*	1.5	4.64	1.2	49.1
MK	Mid	56	24	78	<1	30	94	16	12.1	2.0	119	8.71	8.00	21.5	0.0	1.00	1.4	56.3
ML	Mid	100	46	97	<1	45	92	21	9.1	11.0	93	9.33	7.69	20.7	1.8	0.8	1.8	91.2
MP	Mid	0	12	3	<1	340	433	4	223.7	1.0	142	7.51	6.90	25.2	2.8	2.00	1.3	52.6
MWl	Mid	71	14	7	<1	38	73	11	13.7	4.0	87	8.59	7.16	23.0	0.0	0.33	1.4	74.9
MWp	Mid	87	34	37	<1	8	78	13	12.4	3.0	101	9.01	7.44	23.8	1.8	1.27	1.6	77.7
UHa	Upper	100	50	59	<1	73	154	29	11.0	10.0	93	9.19	7.91	21.2	1.0	0.8	1.7	91.1
UHu/K	Upper	29	16	75	<1	5	83	5	34.3	0.5	102	8.81	6.94	26.0	0.6	1.00	1.5	76.4
UK	Upper	56	34	119	<1	31	145	14	21.4	1.0	65	8.89	7.45	21.6	1.2	3.00	1.8	93.0
UL	Upper	100	42	156	<1	81	125	26	9.9	14.0	88	9.68	7.73	19.5	1.6	1.18	1.8	93.8
UWl	Upper	71	22	8	<1	64	91	18	10.4	9.0	75	8.85	7.18	21.5	0.0	0.29	1.7	92.1
UWp	Upper	87	38	75	<1	10	58	12	10.0	3.0	90	8.98	7.44	22.5	0.2	1.60	1.6	84.4

Table 3-2. Simple correlation coefficients (r) between percent forest cover in each watershed and water chemistry, biology, and habitat scores. Values in bold are significant ($p<0.05$). Values with asterices have been transformed. Transformations were $\log_{10}(x+1)$ except forest cover (asin(square root)). HSBP habitat scores were calculated as a percent of 8 metrics since velocity/depth and embeddedness were not complete for each site.

	Forest Cover			
Variable	All Sites	Low Elevation	Mid Elevation	High Elevation
HSBP	**0.85**	**0.87**	**0.86**	**0.88**
Chlorophyll a	**0.55**	**0.84**	0.70	0.24
Nitrate/Nitrite*	-0.25	-0.51	-0.61	0.71
Total N*	**-0.48**	-0.58	-0.68	0.35
Total P*	**0.71**	0.60	0.77	**0.89**
N:P	**-0.63**	**-0.80**	**-0.84**	**-0.82**
Ortho-phosphate*	**0.65**	**0.76**	0.38	**0.86**
Conductivity*	**-0.56**	**-0.92**	-0.78	0.15
Dissolved Oxygen	**0.71**	0.53	**0.98**	**0.82**
pH	0.36	-0.05	0.66	**0.91**
Temperature	**-0.67**	-0.61	**-0.81**	-0.80
Total Suspended Solids*	0.13	0.53	-0.35	0.35
Turbidity*	-0.45	-0.62	**-0.66**	-0.17
HSVAP	**0.61**	0.36	**0.92**	0.52
HSBP Habitat	**0.56**	0.40	**0.91**	0.60

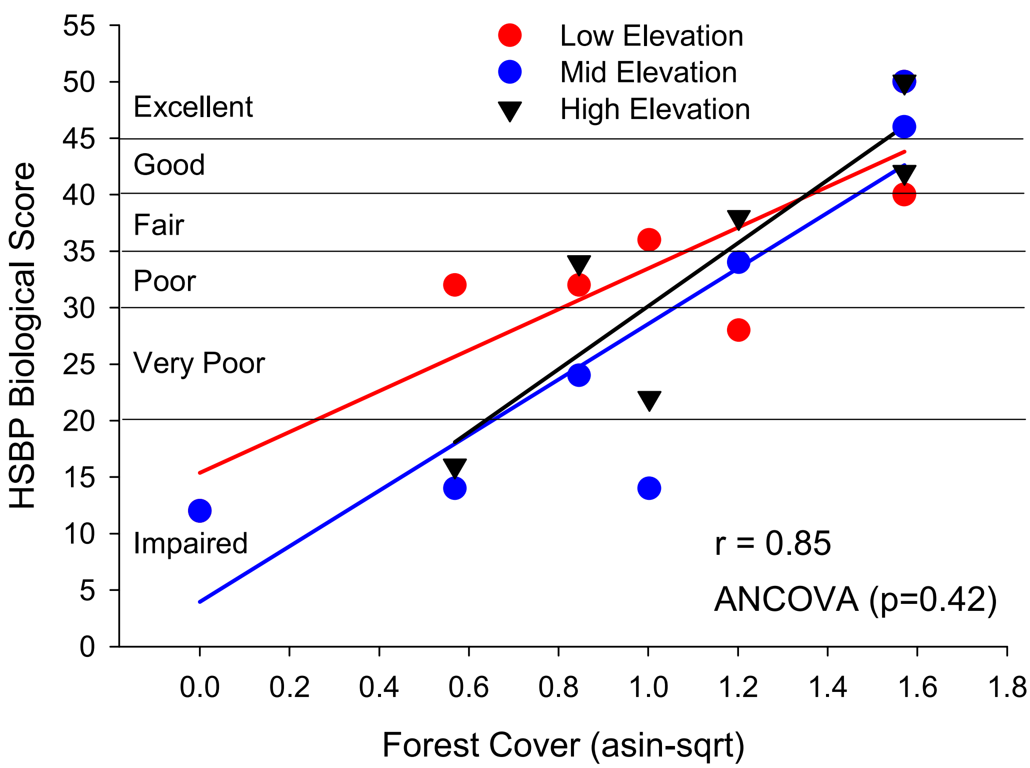

Figure 3-1. Relationship between forest cover and HSBP score for each faunal zone. Biological condition bands given are from Kido 2002. Pearson correlation and analysis of covariance results are also shown.

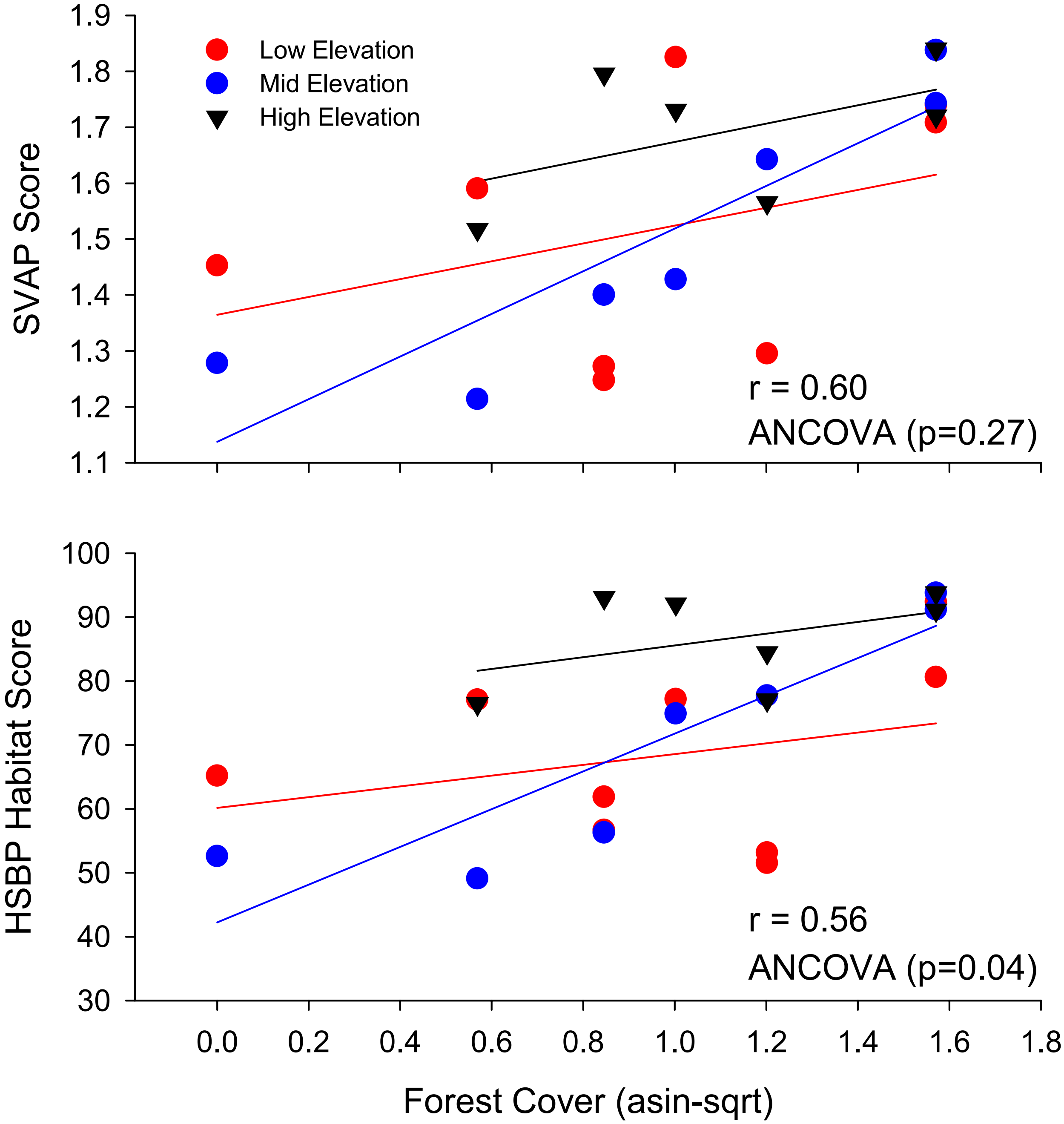

Figure 3-2. Relationship between forest cover and habitat metrics for each faunal zone. Pearson correlation and analysis of covariance results are also shown.

Total nitrogen was negatively correlated with forest cover, suggesting enrichment may be an issue. Three sites exceeded the total nitrogen dry season geometric mean standard (180 µg/L). The highest values were observed in the Middle Puali site (433 µg/L), followed by the Lower Huleia (236 µg/L) and Lower Puali (208 µg/L) sites. The Lower Puali value is a clear outlier among the sites and suggests concern. Nitrate/nitrite represented the predominant form of inorganic dissolved nitrogen as ammonium was never detected in significant concentrations. The nitrate/nitrite dry season geometric mean criterion is 30 µg/L, and more than half (13) of the study streams exceeded this concentration. The mean nitrate/nitrite concentration among sites was 55 µg/L. Even the reference sites, Middle and Lower Hanakapiai had concentrations above the criterion.

The Total Phosphorus response was surprising, as noted above, in that it actually increased with forest cover (range: 4-29 µg/L). None of the sites exceeded the dry season geometric mean criterion (30 µg/L), but a reference site (Upper Hanakapiai) had the highest TP concentration (29 µg/L), which is odd given the amount of sunlight reaching this open canopy site.

Interestingly, as forest cover increased, the N:P molar ratio decreased, and generally dropped below the critical Redfield ratio (16:1), suggesting nitrogen may have been limiting algal growth in forested watersheds. It is conceivable that greater nitrogen and organic matter inputs in less forested streams (from either surface or subsurface inputs) stimulated increased nutrient uptake by heterotrophic organisms, reducing the amount of phosphorus in the water, resulting in the apparent relative "increase" in P with forest cover. In defense of this theory is the fact that nitrogen was higher in less forested watersheds (Table 3-2, Figure 3-3). In general, streams draining volcanic landscapes are perceived as nitrogen limited (Pringle et al. 1990, Pringle 1991, Pringle and Triska 1991, Triska et al. 1993). Within these landscapes, however, the age of the underlying volcanic soils can influence this trend, with younger volcanic soils producing higher P yields than older soils (Chadwick et al. 1999, Schuur and Matson 2001, Hedin et al. 2003). Nevertheless, P yields are still higher in older volcanic watersheds than in most forested non-volcanic regions and dry deposition appears to maintain relatively elevated P yields in older Hawaiian watersheds (Hedin et al. 2003). Higher watershed P yields would explain the generally low N:P ratio of the reference streams in this study relative to non-volcanic landscapes. While these data generally support these interpretations, more data collection would be necessary to verify whether the trends observed here are consistent during the entire year.

3.1.3 Biology and Habitat Responses

Looking at the biological and habitat data in greater detail, both measures were responsive to the gradient in forest cover (Table 3-2, Figure 3-1). This suggests that these metrics are sensitive to anthropogenic impacts on the landscape scale. For the HSBP biological score, more than two-thirds of the variation in biological response could be explained with forested land cover (Figure 3-1). Habitat metrics were similarly predictable using forested land cover. Because these metrics respond to an obvious indicator of anthropogenic stress, it adds defensibility to their use as stream assessment tools in Hawaii.

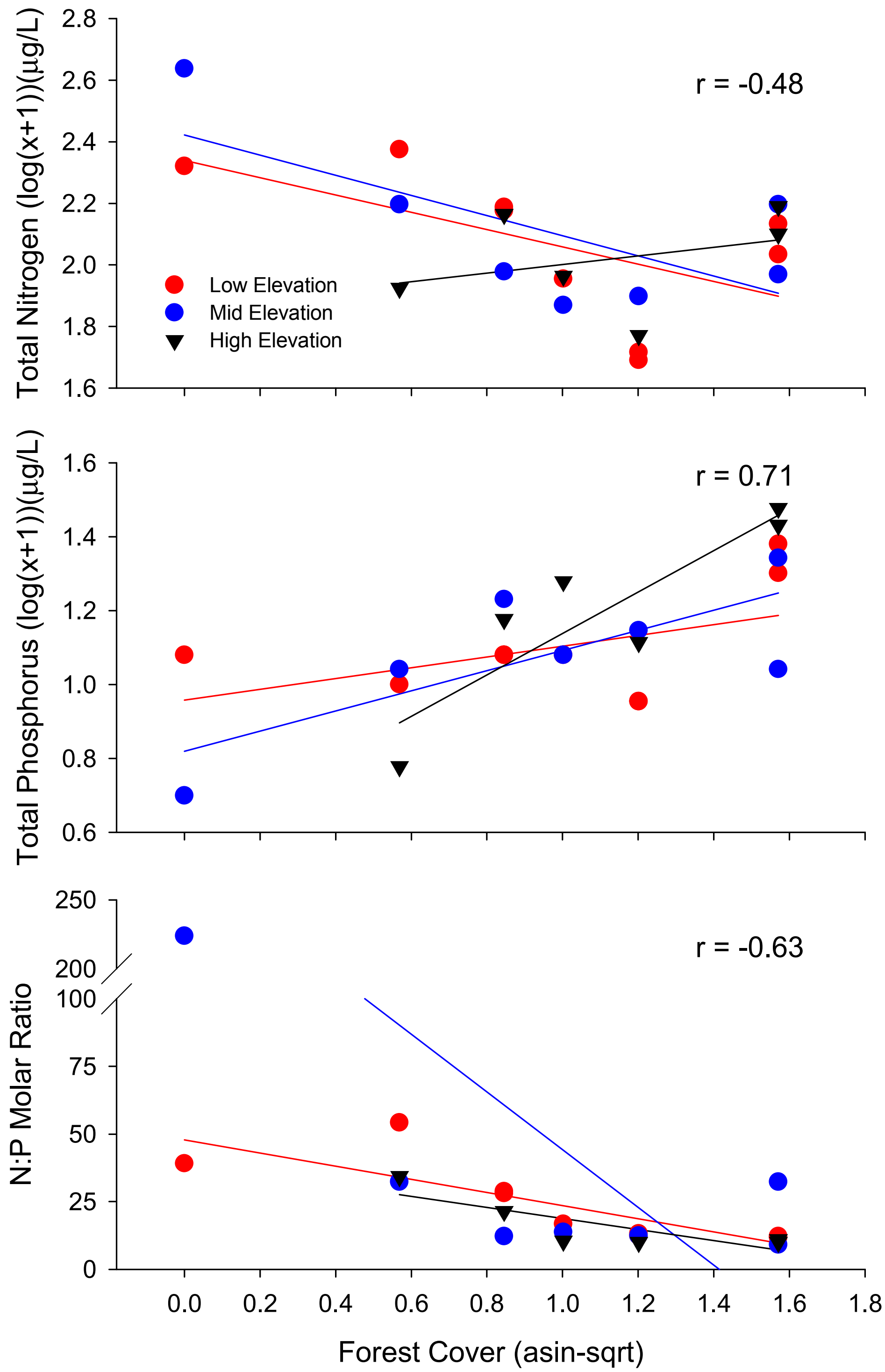

Figure 3-3. Relationship between forest cover and total nitrogen, total phosphorus, and N:P molar ratio. N and P values were log_{10} transformed. Pearson correlation are shown.

The second major question in this study was whether the responsiveness of stream biology and habitat indicators was consistent across the three faunal zones. Having established that the HSBP biology and two different habitat metrics responded to the gradient in forested land use, response of these metrics was explored across the three faunal zones – i.e., was the response of biology and habitat to forest loss the same for each elevation zone? Analysis of covariance (ANCOVA), with forest cover as the covariate and elevation zone as the treatment, was used to explore this question (ANCOVA is explained in detail in the methods). The HSBP and the HSVAP score showed similar responses to the land cover gradient in each faunal zone (Figure 3-2), meaning the decline in scores with forest loss was consistent across low, medium, and high elevation streams. The HSBP habitat trend, however, suggest it may be less responsive to detecting forest loss in smaller, upper elevation sites (Figure 3-2, ANCOVA $p=0.06$). Some scale-dependent metrics in the HSBP habitat index may be contributing to reduced responsiveness to anthropogenic disturbance in higher elevation streams than the biological index or HSVAP. For example, seven out of eight HSBP habitat metrics used had higher means in the upper elevation sites than the other two zones (only Habitat Types was not higher). This was true of the HSVAP as well and is not surprising. In an evaluation of a preliminary habitat index for the State of Maryland, scale dependency was an issue with several metrics (Paul et al. 2003). Smaller streams tend to score better in some habitat indices, likely a result of the steeper slope and the fact that steeper streams may more generally fit perceptions of healthy streams. This phenomenon is worth exploring and correcting if it is an artifact of the method. A possible approach is changing expectations for different elevation streams for most of the metrics instead of just a few. Such calibrations can be made using study designs such as this one.

Another finding with regards to the habitat assessment was the agreement between the two approaches used. Both the HSBP habitat and HSVAP methods were used in each stream. The agreement between the two indices was remarkable (Figure 3-4) and the correlation between the two methods was very high ($r=0.93$), suggesting that both methods were tracking similar visual habitat responses along the gradient. As mentioned earlier, the HSVAP was more robust in its response along the forested gradient at all three elevation zones. The HSBP habitat scores showed less response at high elevation sites. Either method could be used as an indication of habitat condition and the relationship of both to biology is discussed later in this report.

3.1.4 Chlorophyll *a* Response

Chlorophyll *a* varied across the gradient from 0 to 155 mg/m^2 (mean: 56 mg/m^2). These scores were on the lower end for stream periphyton, with values in the 200s considered indicative of nuisance growth. In general, we never observed excess algal growth in any of the streams and the higher levels are likely associated with a few sites containing filamentous algae or mosses.

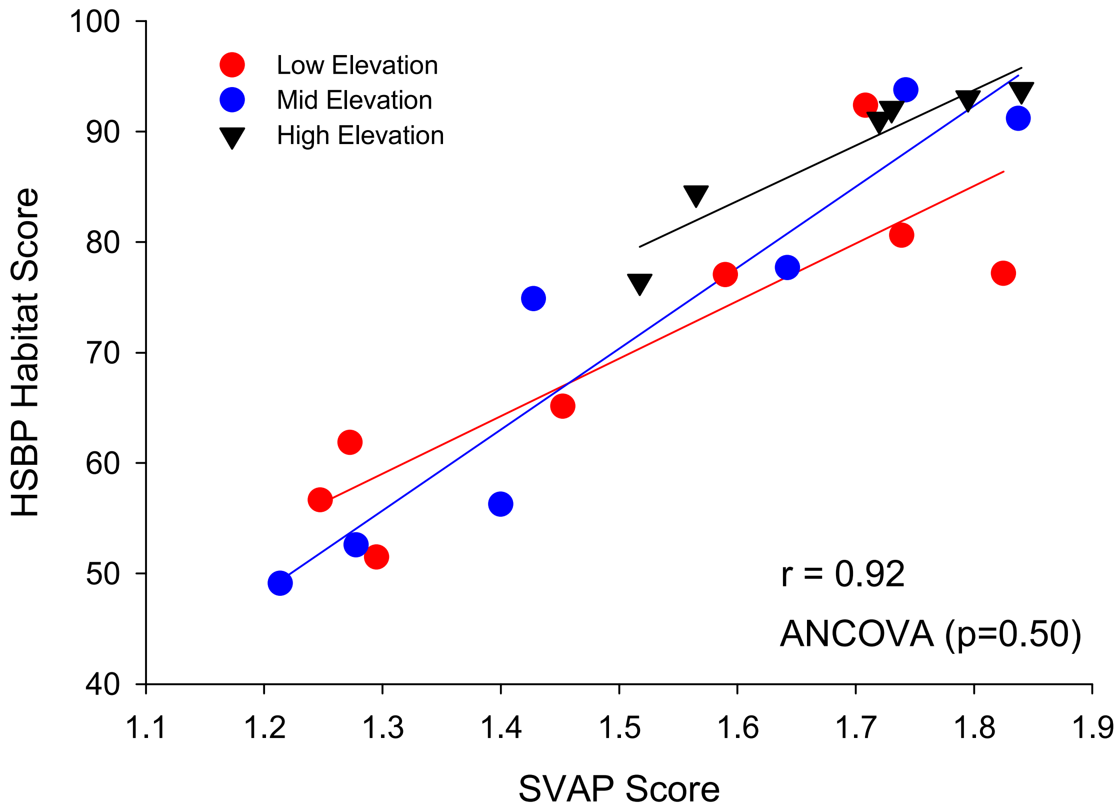

Figure 3-4. Relationship between the two habitat metrics for each faunal zone. Pearson correlation and analysis of covariance results are also shown.

We found very few correlates with chlorophyll *a*, which was surprising given the gradient in nutrient concentrations (Figure 3-5, Table 3-3). Only total phosphorus was significantly correlated with chlorophyll. Both variables were at a generally low range relative to other studies and were actually higher in forested streams. Interpreting this relationship is difficult. Phosphorus can limit algal growth and perhaps higher P levels observed in forested streams were the cause. Light availability and grazing can also affect algal growth. Light was limiting in many streams, where dense overgrowth of introduced trees (e.g., Hau bush, *Hibiscus tiliaceus*; and strawberry guava, *Psidium cattleianum*) shaded streams. Hanakapiai and the middle and upper Limahuli sites were, remarkably, the most open canopied streams. Not surprisingly, they had some of the highest chlorophyll *a* levels. Light may have been an important limitation on chlorophyll accrual, rather than nutrient concentrations. Grazing may have also affected chlorophyll levels, keeping them on the lower range for streams. Algae are an important component of the diet of native Hawaiian stream fishes (Kido 1996, Kido 1997a, 1997b) and their grazing may help suppress algal levels where native taxa are present.

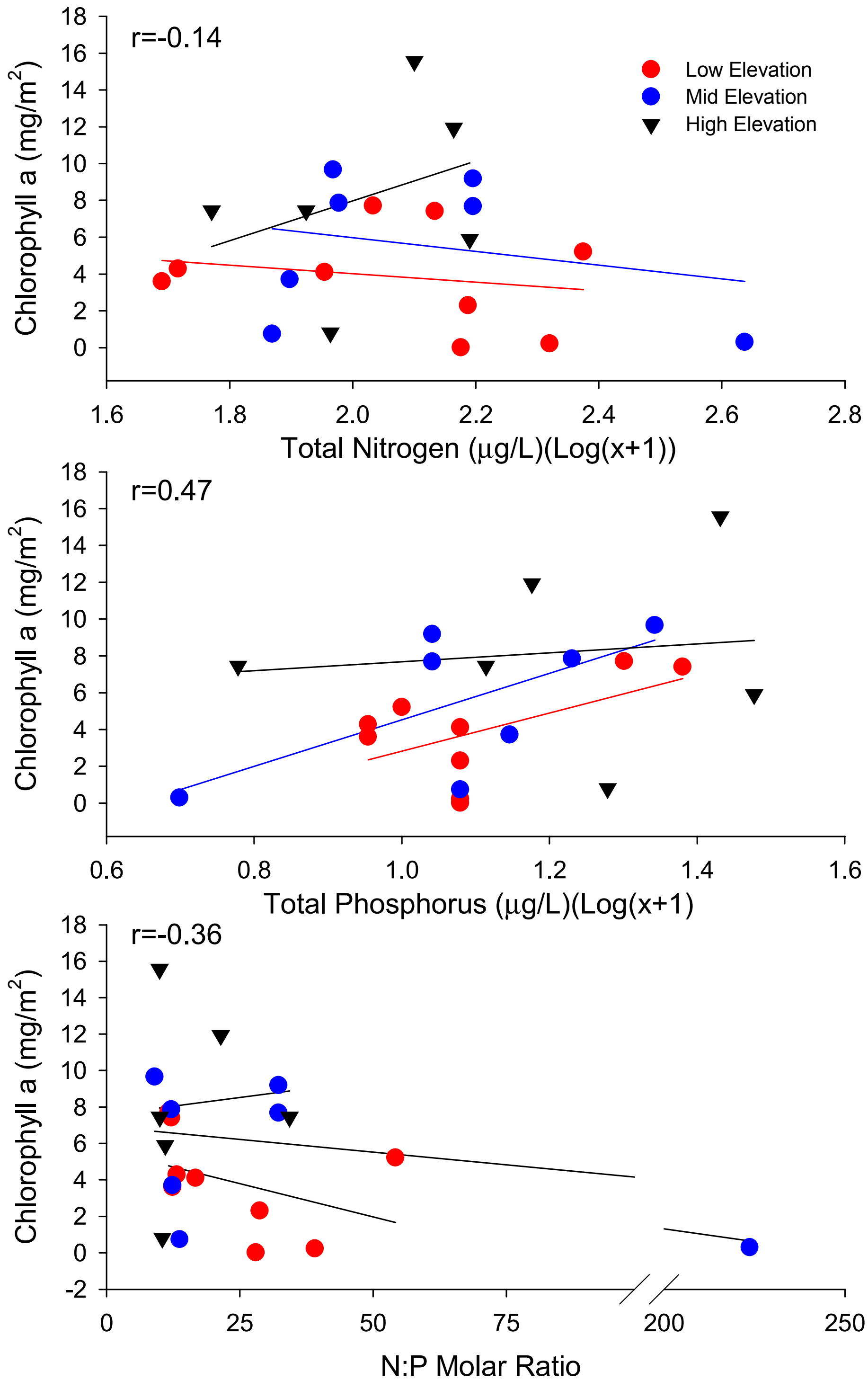

Figure 3-5. Relationship between chlorophyll *a* and total nitrogen, total phosphorus, and N:P molar ratio. N and P values were $\log_{10}$ transformed. Pearson correlation coefficients are shown.

Table 3-3. Simple correlation coefficients between chlorophyll *a* and various water chemistry parameters. Values in bold are significant ($p<0.05$). Values with asterices have been transformed. Transformations were $\log_{10}(x+1)$. HSBP habitat scores were calculated as a percent of 8 metrics since velocity/depth and embeddedness were not complete for each site.

Variable	Chlorophyll a
Nitrate/Nitrite*	-0.11
Total N*	-0.14
Total P*	**0.47**
N:P	-0.36
Ortho-phosphate*	0.31
Conductivity*	-0.45
Turbidity	0.13
HSVAP	**0.48**
HSBP Habitat	**0.44**

In general, chlorophyll *a* responses from this study do not immediately suggest that they will be helpful in exploring nutrient criteria, like they have been recommended or used in other states (Dodds and Welch 2000, Paul and Gerritsen 2002). There are, as noted above, a variety of interactions that affect the relationships and it will likely require a greater range in chlorophyll and certainly a larger dataset to tease the covarying effects out before periphyton chlorophyll can be used to help set targets. A recommendation made in Florida was to perhaps consider downstream impacts of nutrients as a guide to setting upstream limits. That is to say, nearshore eutrophication may better guide allowable nutrient limits for Hawaiian streams. Combined with the generally short length and high flow rates of Hawaii's streams, the difficulty in linking nutrients to instream effects may make it more difficult to derive standards from algal response per se.

3.2 Biological Condition in Kauai Streams and Primary Predictors

3.2.1 Overall Response

Biological condition fell rapidly with decreasing forest cover and values under the least forest cover were quite low (Figure 3-1). Four sites fell into the impaired category, according to percentages of the reference site scores (Hanakapiai site mean = 50), the method suggested in Kido 2002. Three of the sites were mid elevation sites (Middle Huleia, Middle Puali, and Middle Wailua) and one was a high elevation site (Upper Huleia). The biological status of these sites certainly merits more attention and, perhaps, mitigation. There were also three "very poor" sites (Lower Waipa, Middle Kapaa, and Upper Wailua). These sites were impacted and deserve consideration for protection or intervention to ascertain the cause of impairment and mitigation to prevent further decline. On the other extreme, the Limahuli sites scored in either the excellent or good range, suggesting that conditions there were supportive of healthy biological communities, although the Lower Limahuli site was right on the cusp between fair and poor and may require attention to prevent further decline of a watershed in generally good condition.

3.2.2 Correlates

There were a number of predictable correlates with biological condition and a number of unpredicted relationships (Figure 3-6, 3-7, Table 3-4). HSBP scores were positively correlated with dissolved oxygen and habitat score and negatively correlated with temperature, conductivity, and N:P molar ratio. Oxygen is, of course, crucial to aquatic organisms and low oxygen is stressful to fish and many invertebrates. With increased human activity, increased organic matter inputs, reduced flow, and increased temperature can all lower in-stream oxygen concentrations, negatively affecting the biological community, and this may be reflected in the lower scores seen in streams with lower oxygen. Similarly high conductivity is commonly associated with metals and is frequently negatively correlated with biological condition (Wang and Yin 1997, Herlihy et al. 1998, Paul and Meyer 2001). High temperatures can be stressful to aquatic organisms and a wide range in temperature (from 19.5 to 26.2 degrees) was observed. As mentioned earlier, forest loss and loss of groundwater recharge can lead to greater in-stream temperatures and this would affect the biological communities as well. Habitat is also commonly related to biological condition (Richards and Host 1994, Roy et al. 2003), as it represents the physical template upon which communities develop. Any loss in habitat quality will have negative impacts on biological communities. Lastly, N:P ratios may be indicative of nitrogen enrichment, as described above, and thus a negative relationship is not unexpected.

Unpredicted relationships with HSBP scores include chlorophyll *a* and total phosphorus, which were both positively correlated with biological scores (Table 3-4). Traditionally in freshwaters, one would expect that enrichment and associated excess algal growth might be associated with lower oxygen and, therefore, a decline in biological condition (Allan 1995). However, the relationship between P and chlorophyll *a* may be due to some unique features of Hawaiian streams. Hawaiian soils are naturally enriched in P and elevated P may be, in actuality, a natural condition in Hawaiian streams. In addition, some have argued that the natural condition may also be an open canopied stream (M. Kido, University of Hawaii, personal communication). In fact, the Hanakapiai reference stream in this study has a completely open canopy. The introduction of non-native riparian trees (e.g., guava, mango, rose apple, and hau) may actually increase carbon inputs to the stream, including nitrogen in litter and from N-fixing tree species. The effect of N-enrichment might actually stimulate P uptake by heterotrophic bacteria, reducing the instream P concentration. At the same time, the decreased light may limit chlorophyll accrual. This would result in the reduced total P and chlorophyll *a* associated with more impacted sites. This hypothesis could explain the relationship between HSBP scores and total P and chlorophyll *a*, but certainly merits more attention. Either way, chlorophyll *a* and total P were not strong responders to forest loss in this study.

Were the relationships between biological condition and habitat, total P, temperature, and conductivity consistent across the different elevation gradients? An analysis of covariance indicated no significant difference among elevational gradients (Figure 3-6, 3-7). This suggests that biological communities are responding to these stressors consistently across the different faunal zones. This may be due to consistent stressors across the different watersheds (e.g., water diversion or agricultural non-point source inputs).

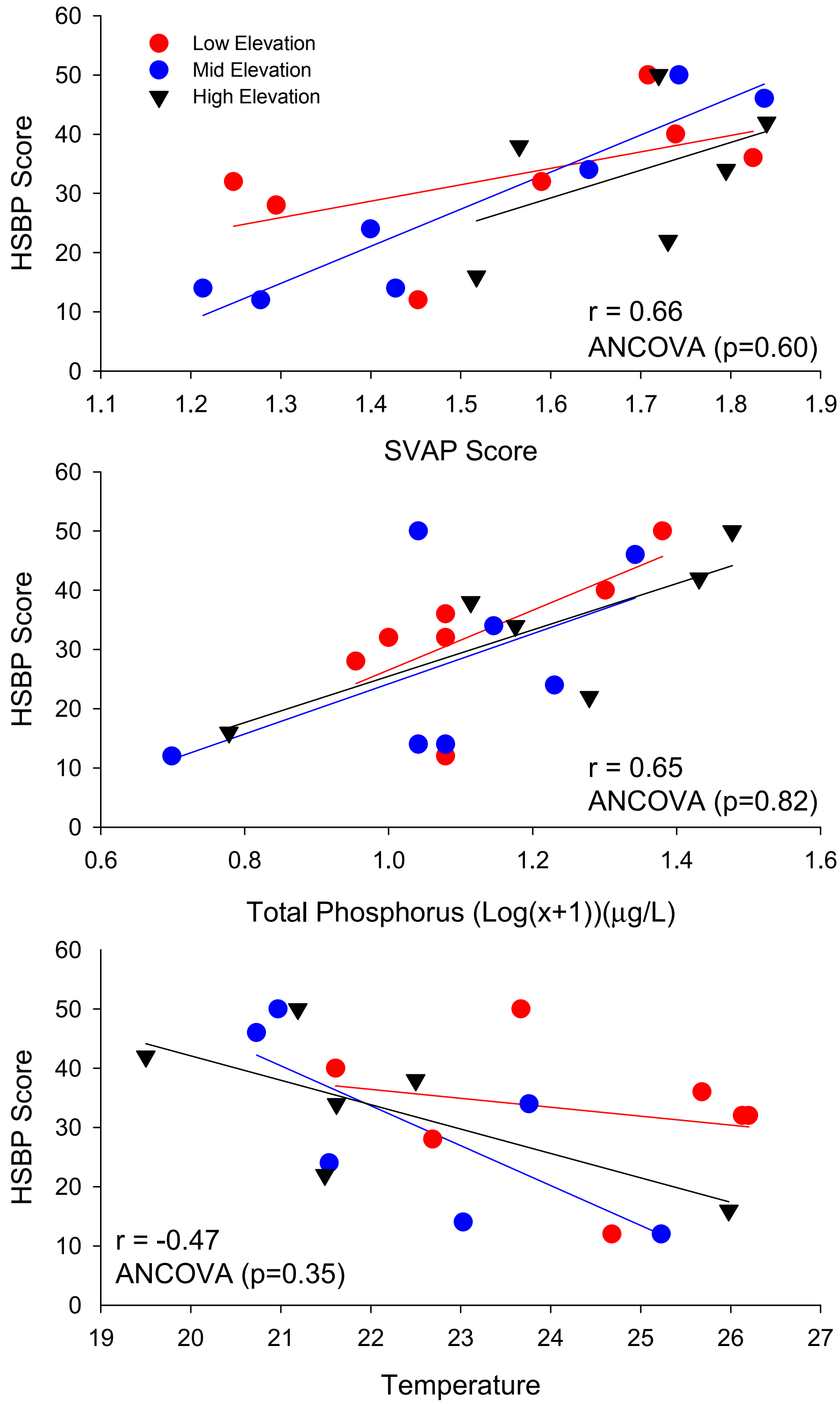

Figure 3-6. Relationship between HSBP score and HSVAP, total P, and temperature by faunal zone. Pearson correlation and analysis of covariance results are shown.

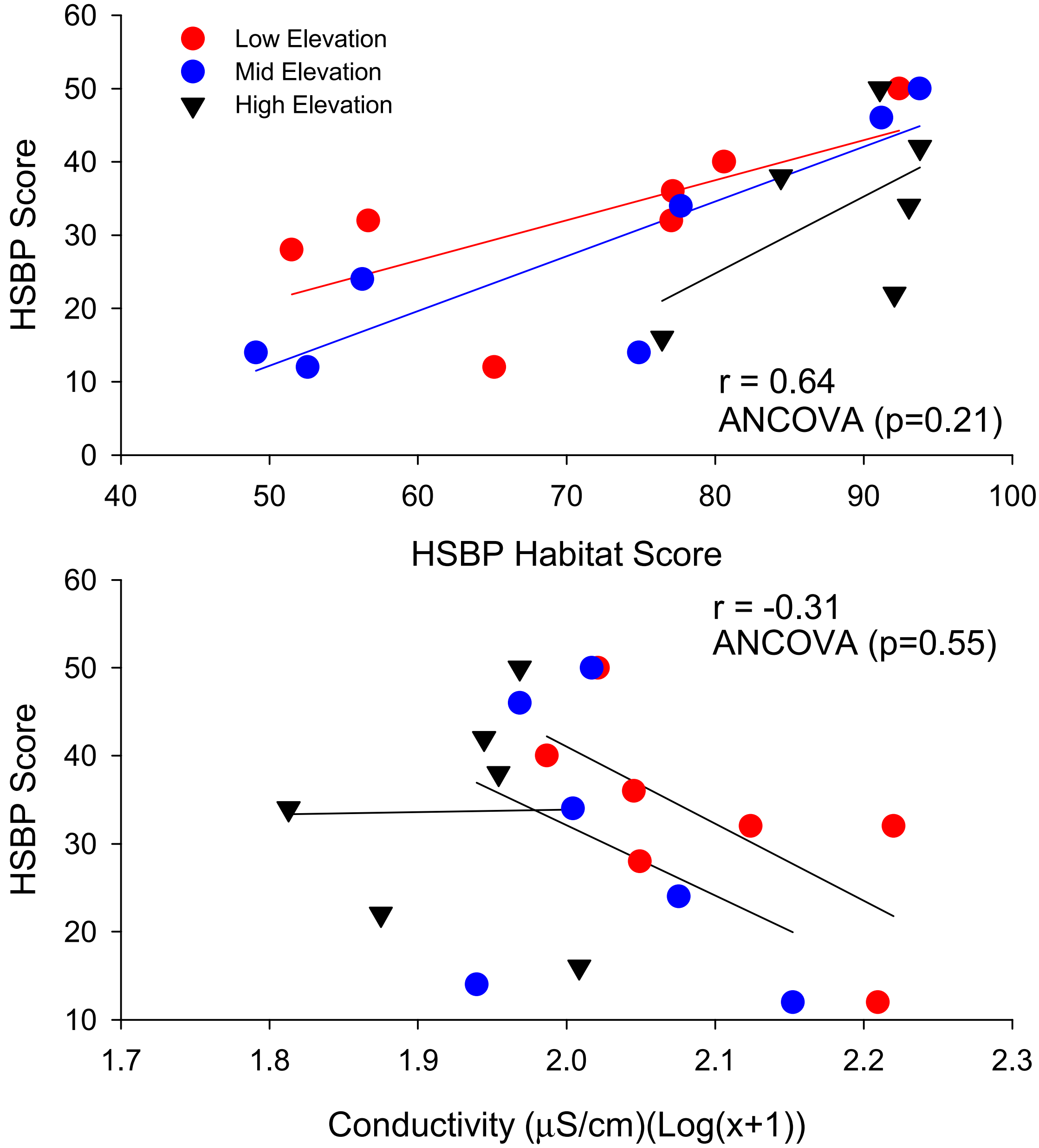

Figure 3-7. Relationship between HSBP score and HSBP habitat score and conductivity by faunal zone. Pearson correlation and analysis of covariance results are shown.

Table 3-4. Simple correlation coefficients between HSBP score and water chemistry and habitat scores. Values in bold are significant ($p<0.05$). Values with asterices have been transformed. Transformations were $\log_{10}(x+1)$. HSBP habitat scores were calculated as a percent of 8 metrics since velocity/depth and embeddedness were not complete for each site.

	HSBP			
Variable	All Sites	Low Elevation	Mid Elevation	High Elevation
Chlorophyll *a*	**0.60**	**0.89**	0.81	0.38
Nitrate/Nitrite*	-0.05	-0.18	-0.33	0.55
Total N*	-0.10	-0.20	-0.27	0.47
Total P*	**0.65**	0.68	0.55	0.78
N:P	-0.44	-0.52	-0.51	-0.66
Conductivity*	**-0.31**	-0.69	-0.38	0.02
Dissolved Oxygen	**0.60**	0.53	**0.90**	0.66
pH	**0.51**	-0.07	0.68	**0.98**
Temperature	**-0.47**	-0.23	-0.74	-0.70
Total Suspended Solids*	0.20	0.48	-0.07	0.52
Turbidity*	-0.04	-0.28	-0.24	0.23
HSVAP	**0.66**	0.54	**0.94**	0.47
HSBP Habitat	**0.64**	0.67	**0.84**	0.56

3.2.3 Best predictors of biological condition

Forward stepwise multiple regression models were used to explore the best set of predictors of HSBP score. Eight variables (chlorophyll *a*, total P, total N, dissolved oxygen, temperature, conductivity, turbidity, and HSVAP) were used in the initial selection procedure. Others were excluded due to colinearity with these variables. Eight variables is still a large number for multiple regression modeling, given that only 20 sites were modeled. In addition, without validation data, one should be careful in extrapolating these model results, but they provide a first approximation for understanding some controls on biological condition across a forest gradient on Kauai. The most significant model selected chlorophyll *a* and total P ($r^2=0.66$, $p<0.05$, Table 3-5). It could be that algae are an important resource for the biological community in these streams and increased chlorophyll is associated with greater potential native biological productivity, especially since nuisance levels of algae were not observed. Previous work indicates the importance of algae in the diets of native fish (Kido 1996, Kido 1997a, 1997b). The variable may also be a surrogate for other factors that reflect the native habitat condition (e.g., open canopy and natural flow) and that support native algal communities. It was surprising, however, that habitat was not selected, given its high correlation with biological condition. However, this may have been a statistical artifact, given the small sample size. Multiple regression models were run where habitat was forced into the model and other important variables were explored. In these models, HSVAP and dissolved oxygen enter ($r^2=0.58$, $p<0.05$, Table 3-5). These models are, in fact, not that different statistically from the unconstrained model. Habitat, algae (an important food resource), and oxygen are important factors to natural communities and this is reflected in the variables that emerged from the multiple regression analysis as important predictors.

Table 3-5. Multiple regression parameter coefficients, significance, and multiple r-square values for predicting HSBP scores. The first model used a forward-stepwise selection method of the following parameters: chlorophyll *a*, total N, total P, conductivity, dissolved oxygen, temperature, turbidity, and HSVAP. The second model had HSVAP forced into the model. Other variables were co-linear with one or more of the included variables and were removed. Both models were significant ($p<0.05$).

Model 1 – All Variables Considered

Variable	Coefficient	p-value	Model R^2
Intercept	-12.29	0.26	0.66
Chlorophyll *a*	20.20	0.005	
Total P	26.12	0.02	

Model 2 – HSVAP forced into model

Variable	Coefficient	p-value	Model R^2
Intercept	-85.00	0.007	0.56
HSVAP	30.55	0.01	
DO	7.85	0.03	

3.3 Existing Standards and Biological Responses

In terms of the standards that exist for Hawaiian streams, there were variations in the levels of constituents relative to state standards. As noted above, the single sample values collected in this study cannot be used to calculate geometric means, therefore values cannot be statistically compared to the state dry season geometric standard. The standard was used as a benchmark for comparison, and the values collected as a basis for future attention. Biological condition did tend to decrease with increasing nitrogen, lending support to the idea that this nutrient may be of central concern for Hawaiian streams. This was reflected, also, in the response to N:P ratio. Total nitrogen concentrations were higher than the dry season geometric mean standard (180 µg/L) in watersheds with less than 20% forest and very low biological scores. If the true geometric mean values are similar to the ones we observed, then biological condition may be responding to even smaller increases in total nitrogen. However, larger sample size across a range of dry season flows would be necessary to verify this. Observed nitrate/nitrite values were higher than the dry season geometric mean standard (30 µg/L) even in the reference streams. If this trend were consistent for geometric means collected from the same sites, it would suggest that the nitrate/nitrite standard may be set too low, at least for protecting biological condition. Calculating geometric means across a forested gradient with concomitant biological data would help clarify this issue. Lastly, HSBP scores increased with total phosphorus concentrations, although the dry season geometric mean standard was never exceeded. This could have been due to a biological enrichment effect, and was discussed in greater detail above.

4. CONCLUSIONS/RECOMMENDATIONS

Care must be taken in interpreting these responses. Again, true estimates of the geometric mean and 2% values must be derived from more than just one sample, they are simply used as benchmarks for comparison here. The 2% standards were not exceeded during this sampling period, except for total nitrogen in the Middle Wailua site (344 µg/L). The same is true for the turbidity and total suspended solids standards. However, this presents the dilemma that biological condition is clearly impaired in many of these streams, few of which, then, had values in excess of the 2% standard. It may be that more nutrient sampling would have uncovered nutrient problems. Certainly, there were high nitrogen values. Or, it may be that nutrients were not the prime culprits. It is important not to derive too much from the results of the study with regards to standards, however, because it was not designed to evaluate compliance with water quality standards or to evaluate existing standards. More samples would be necessary to estimate the geometric mean or 2% exceedance values. This discussion is included primarily to encourage future investigation of water quality standards in relation to biological condition. More frequent sampling of water chemistry and seasonal biological sampling (including algae, invertebrates, and vertebrates) across a gradient in stream condition might help identify more concrete thresholds in nutrient concentrations associated with impacted in-stream biological condition. On the other hand, in freshwater systems such as Hawaii's where the distance between headwater and receiving water (ocean) can be very short and light levels often low, it may be harder to derive relationships between nutrient concentrations and biological condition, especially algae. In this case, the receiving water biological condition may be an alternative guide for setting nutrient standards for island streams. Concentrations for streams could be derived that guarantee that nitrogen and phosphorus concentrations in receiving bays and coastal areas do not exceed those that lead to coastal eutrophication.

This study was designed to evaluate the relationship between habitat, chemistry, and biological indicators. Clearly, the three are related. The strongest relationships exist between habitat and biology, which respond similarly to the land cover gradient, supporting their use in stream evaluation in Hawaii. The relationship between biology and chemistry was less clear. Certainly, biological condition declined with nitrogen, a nutrient of concern. The relationship with phosphorus was more ambiguous. Although the continued use of habitat and biological condition in evaluating streams is encouraged, the ability to extrapolate to nutrients as stressors from biological and habitat data is not clearly demonstrated. It may be that macroinvertebrate or algal community data will provide clearer relationships with nutrient concentrations and it is recommended that the plant and animal samples taken as part of this work be analyzed for potential use in monitoring.

Future work should benefit from this study. Both biological and habitat indices used in this study responded to the human disturbance gradient (represented by forest cover). This strengthens the support for the use of these indices in monitoring stream condition in Hawaii. In addition, significant correlations among habitat indices and between each habitat index and HSBP scores suggest that either habitat index can be used, but both are not required. A short companion report is being developed that makes recommendations on future sampling effort and it will look at the habitat protocols more closely for potential improvement. Important, but challenging, relationships discovered between biological and chemical data suggest that future biological sampling projects continue to incorporate water chemistry sampling. It is recommended that a range of streams sampled for biology also have enough replicate water samples taken to estimate geometric mean and percentile values. This will allow greater confidence in evaluating relationships between water chemical standards and biological condition.

Another important recommendation is the extension of the study design and sampling approach to other islands. Obviously, sampling as many reference streams as possible will increase the dataset from which future improvements in stream monitoring and stream criteria will be made. Verifying that trends in biological condition observed with habitat and some chemical measures on Kauai are consistent across the state will improve confidence that the sampling approach and interpretation are robust for any stream in the state.

4.1 A Role for Aquatic Life Use Standards (ALUS) in Hawaii

The clean water act was written to protect the physical, chemical, and biological integrity of the nation's waters. Historically, chemical and physical standards have been used as substitute criteria for biological integrity, the idea being that if these factors are closely related to biological response, they should be good indicators. Our data suggest that this is not necessarily true. This finding is not unique to Hawaii and has been the reason for recent moves to implement direct aquatic life use criteria for aquatic systems nationally, and aquatic life use standards have already been adopted in some states (e.g., Ohio and Maine, Davies et al. 1995, Yoder and Rankin 1995).

The lack of clear agreement between biological condition and several water chemical parameters, combined with the clear response of biology to forest loss would suggest that direct aquatic life use standards might be a more powerful tool for protecting stream biological integrity in Hawaii as well. For example, using the Hanakapiai stream as a guide, 80% of the HSBP average was equivalent to an HSBP value of 40. Even at 90% forest cover, there were sites scoring below 40. There were HSBP scores of 68% of reference (poor HSBP value, see Figure 3-1) in watersheds with 80-90% forest. This suggests even minor human development was associated with degraded conditions. Aquatic life use standards may offer a powerful way of monitoring to prevent this loss, especially when other surrogate standards are not providing clear and/or adequate protection.

Hawaii and Kauai, in particular, harbor a unique national ecological treasure. The continued protection of their valued aquatic resources will require tools that best track their biological condition. The results here suggest that chemical standard surrogates may not provide the most protection of overall stream integrity. Physical habitat scores are clearly promising and were strongly related to biological condition in all three faunal zones. The development of aquatic life use standards using direct measures of biological condition, like the HSBP, may provide the greatest hope for overall stream protection.

5. LITERATURE CITED

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Appendix 1 – Site Assessments

Lower Puali (7/20/03; 7:30-12:30). This site is in the lower elevation of the Puali stream. The dominant bottom substrate was hard pan clay, the majority of the reach covered riffle/run habitat. Water level was stable. The reach was 102.25m long, and an average of 3.3m wide. The riparian zone was relatively wide, with little disturbance. There was an automated stormwater sampler installed near the downstream section of the reach.

Middle Puali (7/20/03; 14:30-17:00). This site is in the middle elevation of the Puali stream. The dominant bottom substrate was hard pan clay, and the majority of the reach covered riffle/run habitat. The water level was stable. The reach was 99m long. White paint was discharged directly into the stream from a stormdrain at least two separate times during the sampling effort (Photos can be found on disk).

Upper Kapaa (7/21/02; 11:30-17:30). This site is in the upper elevation of the Kapaa stream. The dominant bottom substrate was boulder/cobble, and the majority of the reach was composed of alternating cascade/pool habitats. The water level was stable. The reach was 122m long, and 9m wide on average. A spring entered the stream from the left bank in the 5th segment.

Lower Kapaa (7/22/03; 9:00-14:30). This site is in the lower elevation of the Kapaa stream. The dominant substrate was cobble/gravel, although runs were heavily embedded with fines. There was a bridge culvert about 30m below the downstream flag. There was a mixture of riffle/run/pool habitat available. The reach was 212m long, and averaged 9m wide.

Upper Limahuli (7/23/03; 11:30-14:40). This site is in the upper elevation of the Limahuli stream, above the botanical gardens. Boulder/cobble substrate dominated the streambed. Cascade/run habitats were available. The water stage was stable. Forest cover was 100%, although the watershed had evidence of substantial hau outcroppings. A hau control program was removing the trees along the stream before and after our samples were taken. The reach was 120m long, and averaged 4m in width.

Middle Limahuli (7/23/03; 15:30-18:00). This site is in the middle elevation of the Limahuli stream, above the botanical gardens. The water stage was stable. Bedrock/boulder were the primary substrates along the channel. The dominant reach type was cascade/run/pool. Forest cover was 100%. The hau restoration project was just downstream of the downstream flag for the 120m reach. The average stream width at this site was 6m.

Lower Limahuli (7/26/03; 10:00-12:50). This site is in the lower elevation of the Limahuli stream, running next to the Limahuli Botanical Gardens, with the bottom of the sampling reach approximately equal with the location of the Botanic Gardens Main Building. When sampling began, the water stage was stable, however, it rained during the sampling, and water began to rise quickly and become very turbid near the completion of sampling. GPS coordinates were not available at this site, due an inability to obtain satellite coverage through the storm clouds. The dominant substrate was boulder, with cascade/pool habitats. The reach was 127m long, averaging 6m in width.

Upper Hanakapiai (7/25/03; 12:45-14:30). This site is in the upper elevation of the Hanakapiai stream, about one half-mile below the falls. Occasional spurts of rain fell during the habitat sampling, but did not affect the stream turbidity or other physical measurements. The water stage remained stable. Boulder substrate was available in cascade/ pool habitats. The surrounding watershed is 100% forested. The reach was 179m long, and averaged 6m in width.

Middle Hanakapiai (7/25/03; 8:30-12:30). This 200m reach is located in the middle elevation of the Hanakapiai river, along the Halalau trail. The average width was 8m. The water stage was stable. Dominant bottom substrate consisted of boulder, with cascade/pool habitats available.

Lower Hanakapiai (7/24/03; 14:00-16:45). This 200m reach averaged 8m in width. It is located along the Halalau trail, about one quarter-mile above where the mouth of the river meets the ocean. The channel was composed of boulder/cobble substrates, with cascade/run/pool habitats available.

Upper Huleia/Kamooloa (7/28/03; 12:30-15:30). This site is in the upper elevation of the Huleia watershed, on the Kamooloa tributary. Forest cover in this watershed was only 29%. The bottom substrate consisted of rock and boulder, with cascade/pool habitat available. The water stage was stable. The reach was 120m long and had an average width of 5m.

Lower Huleia (7/29/03; 10:00-13:40). This 180m reach is located in the lower elevation of the Huleia river. The reach began about 75m upstream of the stone bridge. The stream is relatively narrow at that point, however, the upstream portion was very wide, bringing the average width up to 20m. Boulder/cobble made up the streambed. The dominant habitats were riffles and pools. The site was obviously impaired by flow modification. There were extensive mid-channel bars with thick vegetation.

Middle Huleia (7/29/03; 15:30-18:30). This site is in the middle elevation of the Huleia stream, at the halfway bridge. The average width of the stream at this site was only 6m, therefore the reach length was only 100m. Dominant bottom substrate consisted of gravel and boulder. Riffles and pools were the available habitats. The water stage was stable. This site was visited twice; during the morning visit, the water was very turbid, most likely due to runoff of cement trucks being rinsed just upstream of the site. The water was still somewhat turbid during sampling, but fish could be seen. There were also a lot of old bridge cement and iron pieces littering the stream.

Upper Wailua (7/30/03; 9:45-13:00). This site is in the upper elevation of the Wailua watershed. It is inside the forest reserve, above the USGS gauge at the upper-most diversion. Bottom substrate was composed of cobble/boulder-sized sediment. Cascade, riffle, and pool habitat were available. The water stage was stable. An eroding trail runs along the left bank. The reach was 193m long, with an average width of 10m.

Middle Wailua (7/30/03; 15:30-18:30). This site is in the middle elevation of the Wailua river. It is also inside the forest reserve, on the northern fork of the river, just upstream of the confluence with the southern fork. The water stage was stable. Cobble dominated the bottom substrate, creating riffle/run habitats. The reach was 143m long, averaging 7m in width.

Lower Wailua (7/31/03; 11:30-15:45). This site is in the lower elevation of the Wailua river. A well-traveled trail runs along the left bank to a falls. The reach begins about 100m downstream of the USGS gauging station. The water stage was stable. Cobble/rock made up the bottom substrate. Riffle/run/pool habitats were available. This portion of the river is fairly wide (20m), therefore the reach was 413m long.

Lower Waipa (8/2/03; 10:00-12:30). This stream runs through the Kamaameah School Property. This site is in the lowest elevation. The reach was about 4m wide, and 103m long. The water condition was stable. The dominant bottom substrate was cobble, creating riffle and pool habitats. The area immediately downstream of the reach was choked with hau.

Middle Waipa (8/1/03; 10:13:15). This site is in the middle elevation of the Waipa river. During the habitat sampling and before the fish sampling, students from the Kamaameah School were tending taro fields alongside the stream. This caused some turbidity, but the flow of the stream was such that most of the sediment washed through fairly quickly. The water stage was stable. Cobble and boulder substrate combined to create cascade/run/pool habitat. The reach was about 8m wide and 113m long.

Upper Waipa (8/1/03; 14:00-16:30). This site is in the upper elevation of the Waipa river. This cascade/pool reach was dominated by boulder/cobble bottom substrate. The water stage was stable. The reach was 103m long, with an average width of 7m.

Appendix 2 – HSBP Biological Data

Stations	Snam Score	PNT Score	SNF Score	Sensitive Native Fish Score	Sensitive Native Fish Size Score	Awaous Size Score	Native Fish Density Score	CWA Score	NAT Score	Percent Tolerant Alien Fish Score	HSBP Score
LHa	5	5	5	5	5	5	5	5	5	5	**50**
LHu	5	5	1	1	1	5	5	5	1	3	**32**
LK	5	5	1	1	1	5	5	5	1	3	**32**
LKQC											
LL	3	5	3	1	5	5	5	3	5	5	**40**
LP	1	1	1	1	1	1	1	1	3	1	**12**
LWl	5	5	1	1	5	5	3	5	1	5	**36**
LWp	5	3	1	1	1	5	5	3	3	1	**28**
LWpQC											
MHa	5	5	5	5	5	5	5	5	5	5	**50**
MHu	1	1	1	1	1	1	1	1	1	5	**14**
MK	5	1	1	1	5	5	1	1	3	1	**24**
ML	5	5	5	3	5	5	3	5	5	5	**46**
MP	3	1	1	1	1	1	1	1	1	1	**12**
MWl	1	1	1	1	1	1	1	1	5	1	**14**
MWp	5	1	1	1	5	5	3	3	5	5	**34**
UHa	5	5	5	5	5	5	5	5	5	5	**50**
UHu/K	1	1	1	1	1	1	1	1	3	5	**16**
UK	5	3	3	1	5	5	1	3	3	5	**34**
UL	5	5	3	1	5	5	3	5	5	5	**42**
UWl	3	5	1	1	1	1	1	5	3	1	**22**
UWp	5	5	1	1	5	5	1	5	5	5	**38**
UWpQC											

Appendix 3 – HSBP Habitat Data. Not all sites had velocity/depth scores, so the HSBP score was derived for just 9 variables (Total Score 9). This was the value used in analysis.

Stations	Habitat Types Score	Embeddedness Score	FBOM/ CPOM Score	Velocity/ Depth Score	Channel Status Score	Altered Channel Score	Bank Stability Score	Riparian Zone Score	Riparian Understory Score	Cobble/ Boulder Score	Total Score	Total Score 9
LHa	20.0	17.0	19.0	20.0	18.0	20.0	12.8	20.0	20.0	18.0	**92.4**	**91.6**
LHu	20.0	15.0	12.0	20.0	13.3	20.0	10.8	16.0	19.0	12.5	**79.3**	**77.0**
LK	11.7	4.0	20.0	20.0	8.0	20.0	4.8	8.0	8.0	8.5	**56.5**	**51.7**
LKQC	11.7	7.0	20.0		17.0	20.0	1.8	8.0	8.0	12.5	**58.9**	**58.9**
LL	20.0	14.0	15.0	20.0	17.0	20.0	11.5	8.0	20.0	17.5	**81.5**	**79.4**
LP	20.0	8.0	10.0	20.0	12.0	20.0	5.1	19.0	16.0	2.2	**66.1**	**62.3**
LWI	20.0	18.0	19.0	20.0	11.0	20.0	4.9	20.0	11.0	19.0	**81.5**	**79.4**
LWp	18.3	3.0	11.0	20.0	13.0	16.3	0.8	8.0	3.0	12.0	**52.7**	**47.4**
LWpQC	20.0	9.0	13.0	20.0	7.3	13.3	2.2	10.0	10.0	9.3	**57.0**	**52.2**
MHa	20.0	18.0	18.0		19.0	20.0	13.7	20.0	20.0	19.3	**93.3**	**93.3**
MHu	15.0	15.0	13.0	14.2	14.0	20.0	6.8	2.0	2.0	5.8	**53.9**	**52.0**
MK	13.8	4.0	18.0	18.3	14.0	20.0	4.5	0.0	0.0	19.8	**56.2**	**52.2**
ML	20.0	18.0	18.0	20.0	17.0	20.0	11.9	20.0	20.0	19.0	**92.0**	**91.1**
MP	13.8	20.0	6.0	13.3	12.0	14.2	3.2	19.0	16.0	0.0	**58.7**	**57.9**
MWl	10.0	20.0	20.0	20.0	10.0	20.0	7.8	16.0	16.0	20.0	**79.9**	**77.7**
MWp	16.3	2.0	18.0	20.0	15.0	20.0	9.1	15.0	15.0	16.0	**73.2**	**70.2**
UHa	19.0	15.0	19.0		18.0	20.0	11.2	20.0	20.0	18.5	**89.3**	**89.3**
UHu/K	14.0	17.0	16.0	20.0	18.0	20.0	9.3	15.0	20.0	10.0	**79.7**	**77.4**
UK	18.0	18.0	18.0		16.0	20.0	16.9	20.0	20.0	20.0	**92.7**	**92.7**
UL	18.0	18.0	19.0	20.0	18.0	20.0	15.3	20.0	20.0	17.8	**93.0**	**92.3**
UWI	16.0	20.0	20.0	20.0	16.0	20.0	15.3	20.0	20.0	20.0	**93.7**	**93.0**
UWp	15.0	1.0	19.0	20.0	15.8	20.0	7.4	20.0	20.0	18.0	**78.1**	**75.7**
UWpQC	16.0	17.0	18.0	17.5	13.0	20.0	16.3	10.0	20.0	10.0	**78.9**	**77.9**

Appendix 4 – HSVAP Habitat Data.

Stations	Average Element Score by Stream	Bank Stability	Canopy	Channel Condition	Channel Flow Alteration	Habitat Available	Litter/ Trash	Percent Embeddedness	Plant Growth	Riparian Condition	Turbidity
LHa	**1.71**	1.80	0.00	2.00	2.00	1.85	2.00		1.83	1.90	2.00
LHu	**1.59**	1.48	1.73	2.00	2.00	1.58	2.00	1.08	0.65	1.90	1.50
LK	**1.25**	1.13	0.90	1.70	2.00	0.43	1.75	0.90	0.88	0.90	1.90
LKQC	**1.27**	1.48	1.23	2.00	2.00	0.28	1.25	1.00	1.05	1.00	1.45
LL	**1.74**	1.75	1.40	2.00	1.95	1.90	2.00	1.50	1.80	1.20	1.80
LP	**1.45**	0.98	2.00	1.80	1.78	1.50	2.00	0.48	1.50	1.50	1.00
LWI	**1.83**	1.38	2.00	1.80	2.00	1.65	2.00	1.85	2.00	1.58	2.00
LWp	**1.30**	0.23	1.28	1.83	1.85	1.03	2.00	1.30	0.83	0.70	1.93
LWpQC											
MHa	**1.74**	1.83	0.00	2.00	2.00	1.90	2.00	2.00	1.80	2.00	1.90
MHu	**1.21**	1.10	0.00	2.00	2.00	1.13	1.00	1.13	1.50	1.60	0.70
MK	**1.35**	1.00	1.73	1.80	2.00	1.35	1.63	0.88	0.80	0.30	2.00
ML	**1.84**	1.78	1.73	2.00	2.00	1.93	2.00	1.25	1.90	1.90	1.90
MP	**1.28**	0.15	2.00	1.78	1.63	1.00	0.50		1.50	1.45	1.50
MWI	**1.48**	0.98	0.00	2.00	2.00	0.50	2.00	1.98	2.00	1.38	2.00
MWp	**1.64**	1.40	1.25	2.00	2.00	1.68	2.00	1.63	0.85	1.63	2.00
UHa	**1.72**	1.65	0.00	2.00	2.00	1.90	2.00	1.75	1.90	2.00	2.00
UHu/K	**1.52**	1.38	0.85	2.00	2.00	1.65	2.00	1.38	1.00	1.23	1.70
UK	**1.80**	2.00	0.50	2.00	2.00	1.95	2.00	2.00	1.50	2.00	2.00
UL	**1.84**	1.60	1.80	2.00	2.00	1.85	2.00	1.45	1.90	1.90	1.90
UWI	**1.76**	1.83	0.00	2.00	2.00	1.98	2.00	2.00	1.80	1.98	2.00
UWp	**1.57**	1.33	0.00	2.00	2.00	1.85	2.00	1.75	0.80	2.00	1.93
UWpQC											